Water Quality Review: Sierra Nevada 2009 Lake Monitoring

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Executive Summary

Twenty-one Wilderness lakes were sampled for acid-base water chemistry (e.g., acid neutralizing capacity (ANC), calcium, nitrate, sulfate, chloride, potassium, magnesium, sodium, ammonium, conductivity, and pH) between June and October 2009 as part of Project LAKES, the Sierra Nevada long-term lake monitoring project of the Pacific Southwest Region, USDA Forest Service Air Resources Program. After incrementally increasing the number of lakes sampled each year since 2000, 2009 was the third year that the complete network of lakes was sampled in Class I Wilderness Areas in the Sierra Nevada and southern Cascades overseen by the Pacific Southwest Region of the USDA Forest Service.

There is no current evidence suggesting either acidification or nutrient buildup in the lakes monitored in summer 2009. The lakes sampled largely retain the chemically dilute status that has been evident since 2002. An exception is Patterson Lake, in the South Warner Wilderness of northeastern California, where lake chemistry and transparency have always differed appreciably from lakes monitored in the Sierra Nevada. Different geologic and atmospheric conditions are the probable cause for these differences. Patterson Lake was not monitored in 2009 but will be monitored in 2010, assuming sufficient funding and other resources are available.

Fourteen monitoring lakes have records of between 6 and 24 years in length, long enough for preliminary statistical analysis of temporal change. Thirteen of these lakes were monitored in 2009. None experienced a significant decline in the primary indicator for acidification, acid neutralizing capacity (ANC), to below the pre-2009 range. Also only very minor statistical changes were identified in nitrate concentration, a key indicator of potential nitrification. Statistically significant changes were identified for all constituents except magnesium, but the magnitude of most of the changes was low, often below 0.10 $\mu Eq\ L^{-1}$ per year. Exceptions were increases in ANC (Powell Lake) and calcium (Long Lake) where the changes were almost 1.0 $\mu Eq\ L^{-1}$ per year, potential signs of reduced potential for acidification. Among the minor changes, a decline in sulfate continued (in comparison to the full monitoring record) at Waca and Smith Lakes, both in Desolation Wilderness immediately west of Lake Tahoe. Two other lakes showed statistically significant sulfate declines in 2009. The long-term mean sulfate decline rates at these four lakes ranged from 0.12 to 0.20 $\mu Eq\ L^{-1}$. Because these and other temporal changes were minor, and the duration of records at many lakes is still short, these changes do not appear to warrant further assessment at this time. The full suite of changes is nevertheless detailed in a trailing section of this report.

The 2009 quality control analyses did not identify any new or unexpected issues, and for all QA/QC metrics the 2009 data are on par or better than in prior years. A notable QA/QC result is the continuing shift in 2009 away from persistent anion under-estimation through most prior years to an approximate equivalency of anion under-estimation to cation over-estimation. This shift began in 2008.

Compared to 2007 and many prior years, in 2008 many lakes experienced increases in two major chemical constituents, ANC and calcium. Six lakes also had the highest ANC on record in 2009, with Mokelumne 14's ANC almost doubling. Reasons for these increases are unknown, but these changes are not a cause for concern. Nevertheless these changes are intriguing, and could suggest improved buffering capability on the regional scale, but a longer monitoring record is needed to substantiate this speculation. Neither the 2008 nor 2009 ANC increases were sufficient to trigger a statistically significant change in ANC over the lifetime of the monitoring program. Calcium concentrations decreased from 2008 to 2009 but were still generally within the "noise" envelope of the year-to-year concentration changes. Between 2008 and 2009 two other important constituents, nitrate and sulfate, changed little with nitrate decreasing at most lakes and sulfate increasing at about as many lakes as it decreased.

Project LAKES protocols incorporate sampling of shallow (epilimnion) and deep (hypolimnion) lake zones when a thermal gradient exists. The utility of continuing this practice is up for debate. Comparison of ANC, calcium, nitrate, and sulfate concentrations between near-concurrent sample collections for 36 epilimnion-hypolimnion pairings shows generally similar concentrations for the epilimnion and hypolimnion samples. Specifically, the median difference between epilimnion and hypolimnion concentrations ranged from 15% of the median concentration for calcium down to 0% for nitrate. Exceptions to the general result of relative similarity between epilimnion and hyplimnion concentrations are ANC and calcium at Powell Lake, sulfate at Patterson Lake, and calcium at Long Lake. Reasons for the larger differences at these lakes are not known. The ANC and calcium differences at Powell are evident for all seven years of sample collection and the differences are large compared to other lakes (e.g., epilimnion concentrations at Powell are often one-half the magnitude of the hypolimnion samples). Similarly large differences are evident for sulfate at Patterson for some of the years and slightly less evident for calcium at Long. Ceasing collection of hyplimnion samples would end the possibility of further tracking the epliminion-hypolimnion differences at these lakes. However, arguably the current epilimnion-hypolimnion dataset is adequately large to characterize the current status of differences, and those differences for most lakes and for most constituents are relatively low.

Three recommendations are to:

1) **Continue monitoring all lakes in the network.** The lake sampling is aimed at identifying human-caused changes in lakes in selected California Wildernesses. Because changes can be subtle several years are needed before supportable interpretations about trends in lake chemistry can be made. Continued sampling is needed to determine if the chemistry of the Wilderness lakes is changing, and if so if atmospheric deposition is a cause of the changes. Over one-half of the lakes now have at best records minimally long enough to assess temporal change. Each year the duration of monitoring for each lake grows so that continued monitoring will allow better estimates of trends in more lakes each year.

2) **Consider continuing mid-lake hypolimnion monitoring at three lakes--Powell, Patterson, and Long.** These lakes, particularly Powell, appear to have different water chemistries in the hypolimnion (deep zone) versus the epilimnion (shallow zone). Other lakes with both hypolimnion and epilimnion samples generally have similar chemistries in the two zones.

3) **Continue, in refresher training for lake monitoring staff, or communications from the Regional Air Quality Coordinator, to emphasize comprehensive quality control practices.** In the past a variety of issues have caused minor problems in the quality of the data. For instance slightly different names have been used for the same lake, which can cause confusion both at the analytical laboratory and for the data analyst. Also, mailing labels have had illegible zip codes and inconsistent labeling of sample containers has made their origin (e.g., shoreline or epilimnion) questionable. These are not mentioned to criticize field efforts but rather to point out a few of the many details that can "go wrong". Constant vigilance is needed in both field and laboratory activities to assure the collection of reliable information.

1.0 Introduction

Wilderness Areas are important national resources providing relatively unaltered natural landscapes for our enjoyment and as refugia for a variety of biota. Although watershed activities in Wildernesses are highly constrained, damage to some of these fragile resources is possible through short and long-range transport of air pollutants (Eilers 2003). For instance, Sickman et al. (2003) believe "…that lakes throughout the Sierra Nevada are experiencing measurable eutrophication in response to the atmospheric deposition of nutrients" and Fenn et al. (2003) document elevated nitrate levels in high-elevation Sierran lakes, reportedly from nitrogen deposition. To address this concern, in 2000 the Air Resources Program of the Pacific Southwest Region (Region 5) of the USDA Forest Service (FS) initiated lake monitoring in Class I Wilderness Areas of the Sierra Nevada, California Cascades and northeastern California. A monitoring goal of this program is to provide early indication of possible impacts associated with deposition of acid-rain precursors.

This report assesses and interprets water chemistry data collected in 2009 and compares these data against information obtained in prior years. This report does not directly specify the background context for lake or stream monitoring by the regional Air Resources Program. One objective of the monitoring, however, is to address the management goal of maintaining or improving aquatic, physical and biological air quality related values (AQRVs) of "Class I" Wilderness Areas as mandated by amendments to the Clear Air Act and interpreted by the US Senate as an "affirmative responsibility by federal resource managers to err on the side of protecting AQRVs for future generations" (US Senate 1977).

2.0 Lake Monitoring Network

One intent of the Region 5 lake monitoring program is to follow the precedent of other FS regions by identifying a small number of lakes sensitive to atmospherically-driven acidification in each Class I Area and monitoring them over the long term. The premise is that monitoring lakes (operationally defined as water bodies greater than one hectare in area and greater than two meters in depth) particularly vulnerable to potential acidification will act as "a canary in a coal mine" and that their protection presupposes protection of less sensitive lakes.

ANC is the single best indicator of lake sensitivity to acidification (Sullivan et al. 2001). Lakes with low ANC are sensitive to acidification, and low-ANC lakes provide information relevant to possible nutrient issues. The selection process for long-term monitoring lakes (those with low ANC) is not simple and requires a combination of modeling (Berg et al. 2005) and synoptic sampling prior to final selection. Twenty-one monitoring lakes were sampled in 2009. These lakes were selected after a one-time synoptic sampling of many lakes in each Wilderness in which ANC and other chemical constituents were evaluated. 2009 was the third year that the complete network of lakes was sampled in a standardized manner. The network, including lakes in all Class I Wildernesses ranging from the Sierra National Forest in the southern Sierra Nevada (John Muir Wilderness) to the Modoc National Forest in the northeastern corner of California (South Warner Wilderness), is now complete and no other lakes are anticipated to be added (Figure 1) (Domeland Wilderness, the southern-most Class I Area in the Sierra Nevada, has no lakes and is not included in the sampling network).

In 2009 twenty-one lakes were sampled from eleven Wildernesses as follows:

Wilderness	Number of Lakes Sampled	Long-term Monitoring Lakes
Hoover	2	Moat, Cascade
John Muir	5	E chain, Vermilion, Treasure, E Wahoo, Bench
Kaiser	1	Long
Ansel Adams	3	Walton, Little E Marie, Dana
Dinkey Lakes	1	Bullfrog
Mokelumne	2	Mokelumne 14, Lower Cole Ck
Desolation	2	Smith, Waca
Emigrant	3	Powell, Karls, Key
Caribou	1	Caribou 8
1000 Lakes	1	Hufford

Patterson Lake, in South Warner Wilderness, was monitored each year between 2002 and 2008. Due to staffing limitations, particularly with respect to the distant location of Patterson from the other lakes in the network, Patterson was not sampled in 2009. Assuming the availability of funding, Patterson will be sampled in 2010.

Mid-lake samples were collected at lakes known or expected to be thermally stratified. At other lakes shoreline samples were collected. In addition, shoreline samples were collected with mid-lake samples at five of the lakes to provide information on the option to sample only along the shoreline in the future.

One long-term monitoring lake, Waca in Desolation Wilderness, has been monitored fourteen times since 1985; monitoring of the most of the other lakes began more recently:

Lake	Wilderness	Years of Data	Years Sampled
Powell	Emigrant	9	2000, 2002-09
Key	Emigrant	10	2000-09
Karls	Emigrant	7	2000, 2003-04, 2006-09
Long	Kaiser	9	2000, 2002-09
Patterson	S. Warner	7	2002-08
Mokelumne 14	Mokelumne	8	2002-09
Lower Cole Creek	Mokelumne	8	2002-09
Hufford	1000 Lakes	8	2002-09
Caribou 8	Caribou	8	2002-09
Waca	Desolation	14	1985, 1991-93, 2000-09
Smith	Desolation	10	1985-86, 1991-92, 2000, 2005-09
Walton	Ansel Adams	6	2004-09
Dana	Ansel Adams	6	2004-09
Little East Marie	Ansel Adams	5	2004, 2006-09
Bullfrog	Dinkey Lakes	6	2004-09
East Chain	John Muir	4	2005, 2007-09
Treasure SE	John Muir	4	2005, 2007-09
Vermillion	John Muir	4	2005, 2007-09
Bench	John Muir	4	2005, 2007-09
East Wahoo	John Muir	4	2005, 2007-09
Cascade	Hoover	4	2006-09
Moat	Hoover	4	2006-09

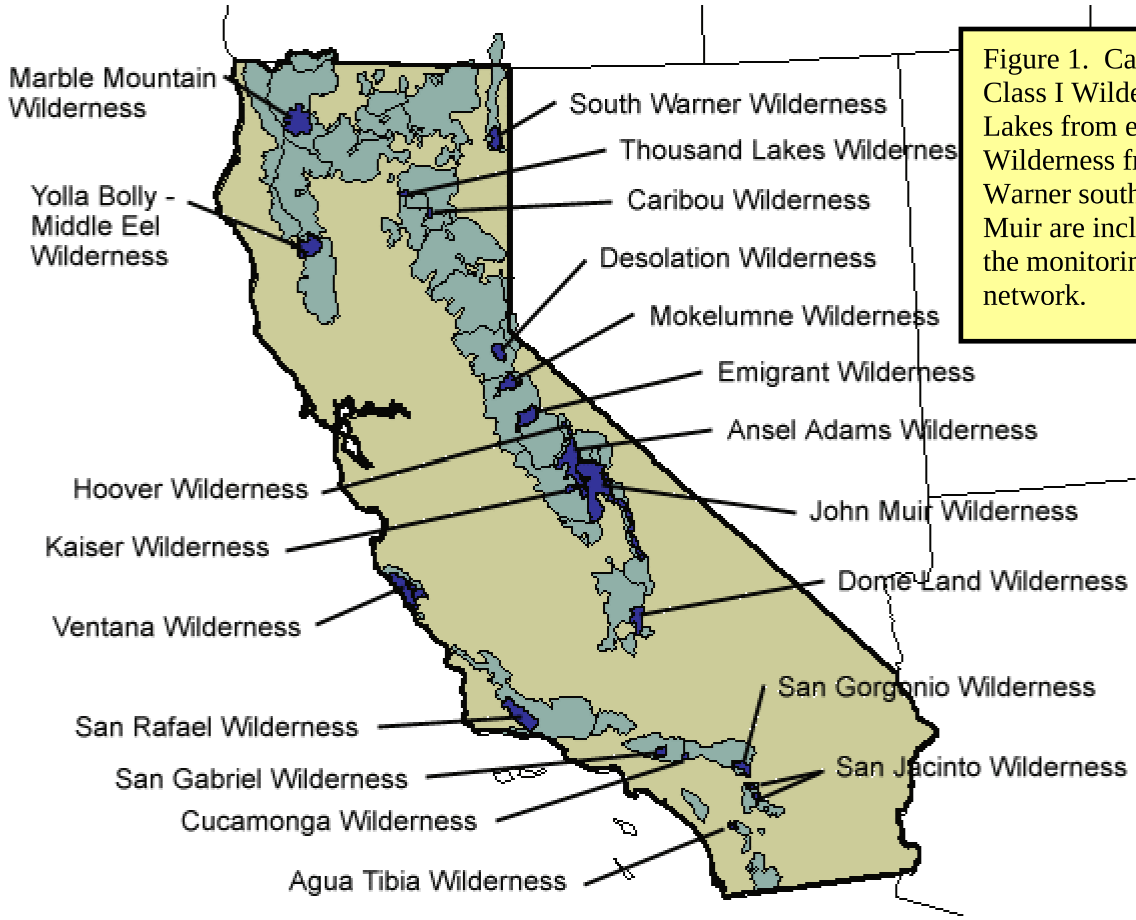


Figure 1. California Class I Wildernesses. Lakes from each Wilderness from S. Warner south to John Muir are included in the monitoring network.

This report addresses lake chemistry in the context of an early-warning monitoring program for acidification of Wilderness lakes. The monitoring program is not a research study, and relatively minor irregularities in the quality assurance results are not presumed to be causes for major concern.

3.0 Objectives

This report has three primary objectives:

1) Assess the quality of selected field procedures and laboratory analyses of lake water samples collected in 2009, specifically to identify any samples that may need re-analysis or that otherwise may require additional action (e.g., revision of sample type/label or deletion of the data).
2) Summarize the relationships between the 2009 lake chemistry data and information collected in prior monitoring (e.g., trends through time).
3) Graphically assess differences in water chemistry between samples collected at shallow (epilimniion) and deep (hypolimnion) lake locations.

This report is not comprehensive in that some components of the 2009 (and earlier) data collection are not evaluated (e.g., 2009 lake transparency, non-chemical data from field data sheets, including water temperature information, and zooplankton data). Nor are other potentially relevant components of the monitoring program comprehensively addressed (e.g., adequacy of training, dataset formalization).

4.0 Methods

To address the quality assurance objective, a variety of standardized techniques are available. This assessment focuses on commonly-used techniques described and exemplified in prior assessments for Forest Service lakes (e.g., Turk 2001,

Eilers 2003, Eilers et al. 1998) and does not include all possible assessment procedures. The procedures evaluate (1) internal consistency of samples (e.g., transit time, ion balances, calculated versus measured ANC, calculated versus measured conductivity, and outlier assessment), (2) precision through analysis of duplicate samples, and (3) bias or sample contamination through assessment of field blanks. Lakes with unexpected chemical concentrations are identified in the outlier assessment. Each technique is described briefly below. The data were analyzed with either the Excel® or WQSTAT Plus® software packages.

All samples were analyzed at the USDA Forest Service Rocky Mountain Station analytical laboratory in Ft. Collins, Colorado (hereafter referred to as RM). Concentrations of the following constituents were assessed: conductivity, calcium, magnesium, sodium, potassium, ammonia, fluoride, chloride, nitrate, sulfate, phosphate and ANC. Acidity, as pH, was also evaluated. Detection limits (mg/L and μEq L^{-1}) are listed below for the major anions and cations:

Sulfate	Sodium	Ammonia	Chloride	Potassium	Magnesium	Calcium	Nitrate
0.04/0.83	0.02/0.88	0.01/0.55	0.02/0.56	0.01/0.26	0.01/0.82	0.04/2.00	0.03/0.48

Several of the monitoring lakes were sampled both near the surface (epilimnion) and at depth (hypolimnion) if they were thermally stratified; otherwise the thermally un-stratified lakes were sampled approximately 1 m below the lake surface at a deep-water location or along the lake's shoreline. To continue to assess potential differences between mid-lake and lake shoreline chemistries, several lakes were sampled at all three locations contemporaneously (outlet/shoreline, epilimnion and hypolimnion) or both outlet and epilimnion concurrently. Specific sampling and monitoring protocols are detailed in Berg and Grant (2004) for the long-term lakes and in Berg and Grant (2002) for the lakes sampled at the outlet or along the shoreline.

Data analysis follows the draft protocol for long-term lake monitoring being adopted by the national Air Resources Program of the USDA Forest Service (Gurrieri 2006). The summarization objective addresses temporal change with time series plots and tests for statistical trends in chemistry for lakes with at least 6 years of data. The data are first checked for normality (Shapiro-Wilk procedure, Gilbert 1987), then trends are assessed by the nonparametric Mann-Kendall test, with statistically significant trends quantified by Sen's slope estimate (Sen 1968). Caution is needed in interpreting temporal trends for Waca and Smith Lakes because sampling over the years has been undertaken by different agencies and chemical analyses conducted at different laboratories. Differences in procedures could confound statistically significant temporal trends. Also the samples for trend analysis are from either mid-lake epilimnion or lake outflow locations. Although differences between these locations are typically understood to be minimal (Clow et al. 2002, Musselman 2004), they could also confound identification of temporal trends.

Recommendations are listed at the beginning of this report and documentation of the 2009 chemistry data is given in Appendix I.

5.0 Results

5.1 Quality Assurance

5.1.1 Internal Consistency

5.1.1.1 Transit Time

After collection, samples need to be kept cool to preserve their chemical integrity. Sample warming elevates the risk of biological activity in the sample that could alter the concentration of some chemical constituents. Although refrigerant is included in sample mailing packages the refrigerant has an unknown, but probably relatively short, effective lifespan. All effort should be made to assure sample arrival at the analytical laboratory as soon as possible after collection. To this end a courier system is sometimes used to expedite shipping of samples from lake to trailhead. If needed, samples are stored in a refrigerator rather than mailed over a weekend.

The critical time period is not the total transit time, but the duration that a sample is kept cool by a short-lived refrigerant (e.g., "blue ice") versus a dedicated coolant (e.g., a refrigerator). Information is not readily available on the time duration

samples were cooled by a short-lived refrigerant so the potential for sample degradation due to inadequate cooling can't be completely assessed. Nevertheless, in general the longer the time between sample collection and receipt at the lab, the greater the chance for sample degradation.

Sixty-five sample collections (including duplicates) were made from the 21 lakes sampled in 2009 (plus two lakes sampled twice). Sixty-four percent of the collections arrived at the laboratory within 3 days of sample collection (compared to 64% in 2003, 62% in 2004, 26% in 2005, 38% in 2006, 38% in 2007, and 58% in 2008). Thirty percent of the collections in 2009 had transit times of 5 days or longer, compared to 27% in 2008 and 54% in 2007. The 2009 mean transit time was 3.5 days, equal to the 2008 mean time, and down from over 5 days in 2007, and from 4 days in 2006. Compared to earlier years, transit times in 2009 were relatively short—a good sign--particularly compared to 2005-2007.

For the third consecutive year samples from the same lakes (collected on the same dates) had differing transit times. In the extreme, the two samples from Bullfrog Lake arrived at the analytical laboratory four days apart. "Duplicate" and "original" samples from some lakes were purposefully sent on different dates, to help assure one or the other was received in a timely fashion. Some of these samples were in transit over a weekend, and therefore had extended transit times. Some lakes with relatively long transit times in 2008 (e.g., Walton, Vermilion and Hufford) also had long transit times in 2009. The reason(s) for these longer transit times aren't known. Their remote location could add to transit time for samples from these lakes.

Transit time (days)			**Number of Lakes**					
	2009	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**
1	0	0	0	1	1	0	0	1
2	28	28	7	6	8	14	3	6
3	13	12	9	6	2	4	4	3
4	4	10	4	3	7	0	2	25
5	8	9	6	6	4	4	1	5
6	7	7	4	2	15	5	0	1
7	4	3	8	6	4	1	1	1
8	0	0	4	0	1	1	0	0
>8	0	0	5	4	0	0	0	0

5.1.1.2 Ion Balance

A basic premise in ion balance determinations is that the sum of the negatively charged constituents (anions) should balance the sum of the positively charged constituents (cations) in each sample. Analytical procedures are not perfect so typically the ion balance is not exact for a set of samples. Ideally, however, there should be no bias; the sum of the cation minus anion concentrations for a set of samples should approximate zero. Bias is often attributed either to laboratory error or lack of testing for one or more cations or anions. Several related techniques address ion balance, either for potential problems with specific samples or as indicators of overall trends among samples.

Considered as a whole, the chemistry of the 2009 lake samples is slightly biased (Figure 2), and has a consistent under-estimation of the anions or over-estimation of the cations. Over 85% of the 2009 non-blank samples have a greater cation sum than anion sum, and there is an overall average of 6.5 μEq L^{-1} cation excess/anion deficiency per sample. This bias compares with averages in 2008, 2007, 2006, 2005, 2004, 2003, 2001 and 2000 of 8.2, 7.5, 13.3, 16.4, 15.9, 9.1, 10.7 and 8.75 μEq L^{-1} respectively. Although continuing cation excess/anion deficiency bias has been evident during every year of sample analysis, by the average deficiency metric the 2009 bias is less than in any other prior year.

A four-quadrant plot (Figure 3) provides additional information on the cation excess-anion deficiency issue. This plot shows that the bias is best characterized as a slight over-estimation of cations. The cation over-estimation is a departure from all years prior to 2008. Through 2007 there was a consistent anion under-estimation. In 2008 (and in 2009) the anion under-estimation approximated the cation over-estimation. The approximate equivalency of anion under-estimation to cation over-estimation is a good sign, and although the reasons for the shift from prior years aren't completely known a laboratory instrumentation change occurred before the 2007 analyses were made. Extensive comparisons between results from the old and new instrumentation showed very similar cation concentrations (L. O'Deen personal communication 3/30/09).

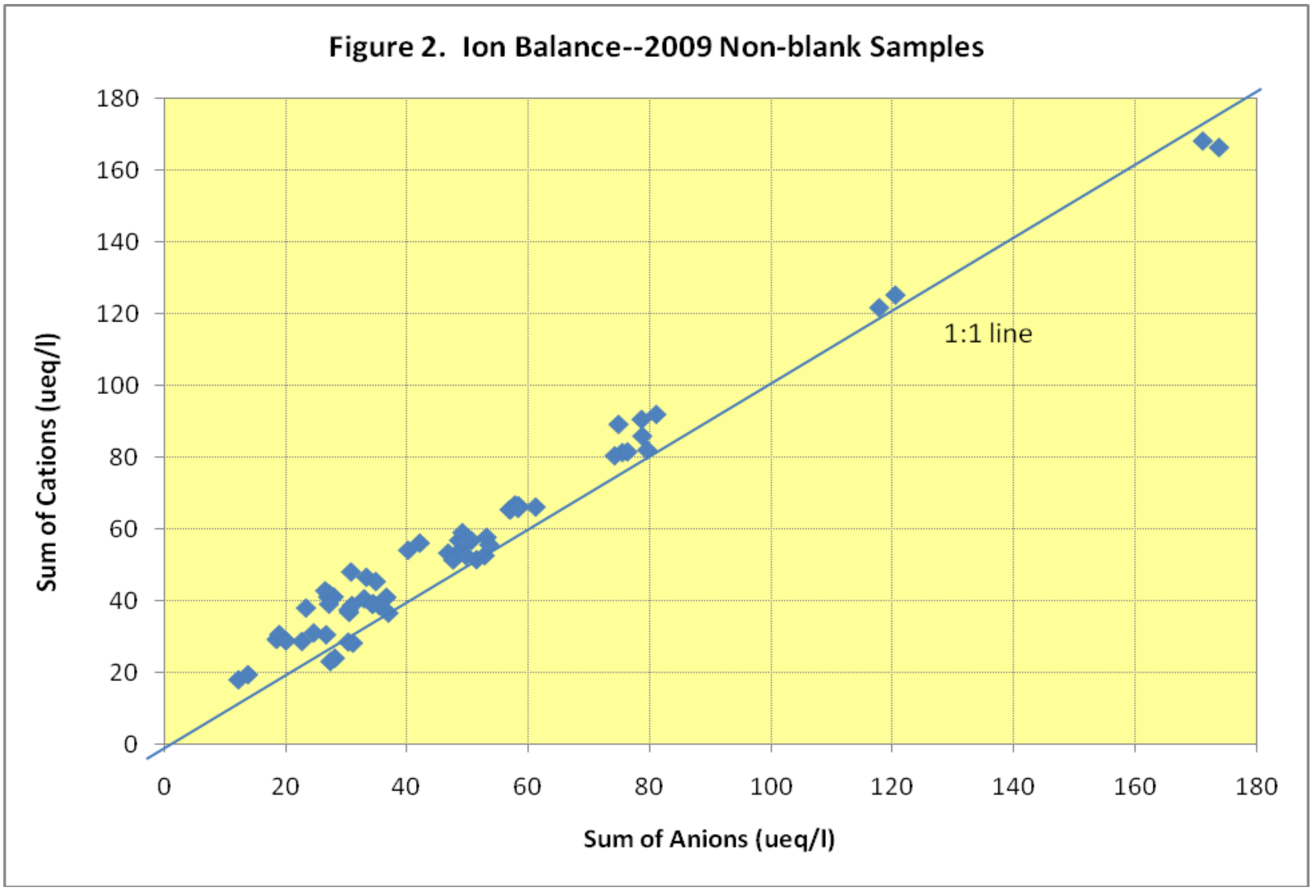


Figure 2. Ion Balance--2009 Non-blank Samples
Sum of Cations (ueq/l)
Sum of Anions (ueq/l)
1:1 line
0
20
40
60
80
100
120
140
160
180

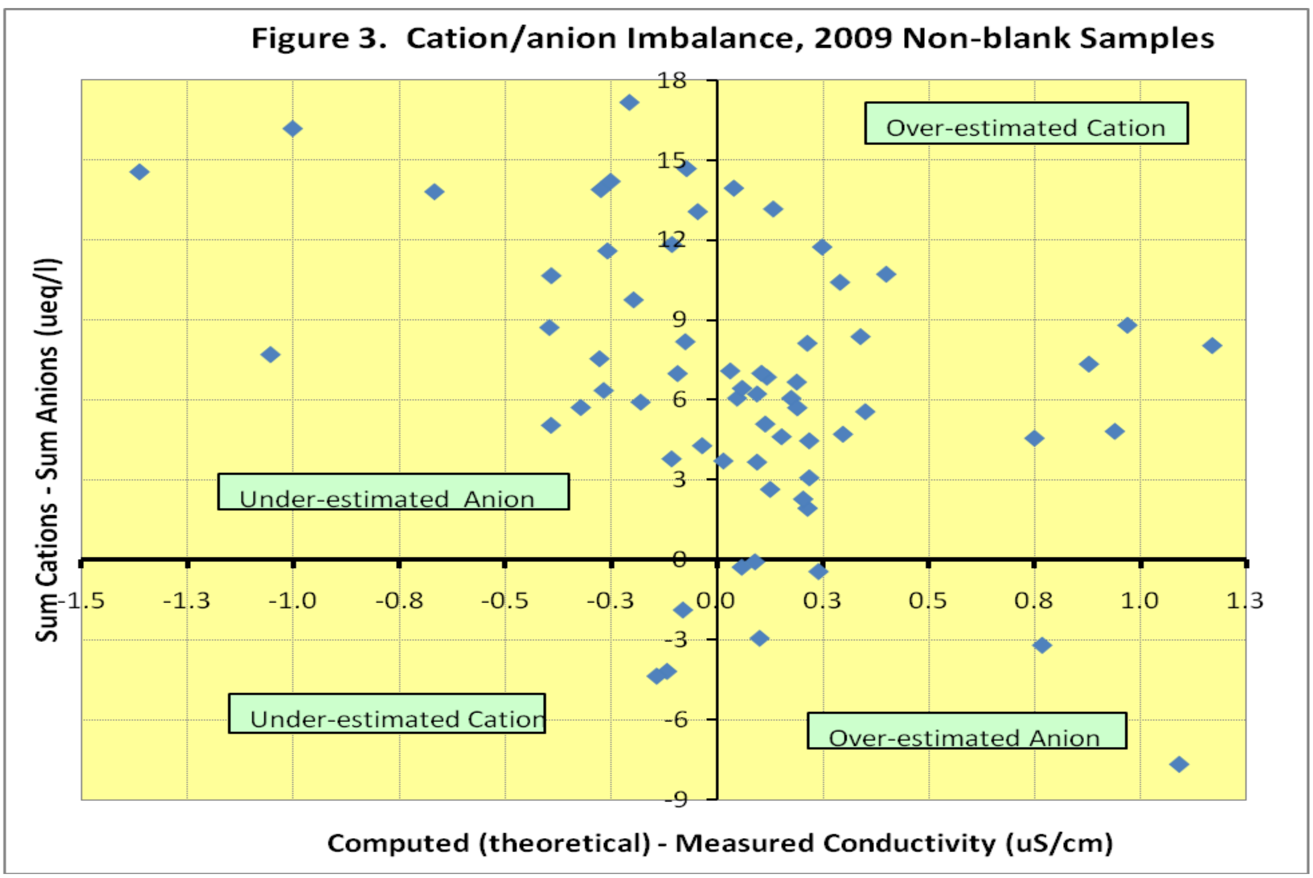


Figure 3. Cation/anion Imbalance, 2009 Non-blank Samples
Over-estimated Cation
Under-estimated Anion
Under-estimated Cation
Over-estimated Anion
Sum Cations - Sum Anions (ueq/l)
Computed (theoretical) - Measured Conductivity (uS/cm)
18
15
12
9
6
3
0
-3
-6
-9
-1.5
-1.3
-1.0
-0.8
-0.5
-0.3
0.0
0.3
0.5
0.8
1.0
1.3

The ion imbalance has been evident during all years of sample collection. Samples from dilute waters in other areas can have a similar imbalance, and the relatively improved bias in 2007 through 2009 (versus earlier years) suggests that the ion balance in 2009 is not a major problem.

5.1.1.3. Cation and Anion Sums

The ion balance calculations in section 5.1.1.2 address the chemistry dataset as a whole. For individual samples Turk (2001) identified two triggering values for cation/anion sum problems—to meet "mandatory" and "higher-quality" levels of data quality:

Total Ion Strength (cations + anions) ($\mu Eq\ L^{-1}$)	**% Ion Difference—Mandatory**	**% Ion Difference—Higher Quality**
<50	<60	<25
50-100	<30	<15
$\geq$100	<15	<10

Both sets of criteria are percent-based and take into account the fact that percentage values increase for the same absolute differences in concentrations as concentration levels decrease. The percent of samples meeting the two criteria are listed below for monitoring years 2002-2009:

Year	**% Meeting Mandatory Criterion**	**% Meeting Higher Quality Criterion**
2009	100	88
2008	99	74
2007	99	85
2006	99	74
2005	91	73
2004	90	20
2003	100	83
2002	100	87

In comparison to earlier years, the 2009 data are comparable in terms of meeting the mandatory standard and better than earlier years in having a higher percentage of samples that met the higher quality criterion. Similar to earlier years, the samples in 2009 that did not meet the higher quality criterion all had low ANC, usually below 25 $\mu Eq\ L^{-1}$.

5.1.1.4 Calculated versus Measured ANC

Another index of potential ion imbalance is the comparison of measured ANC against ANC calculated as the difference in the sum of base cations (calcium + magnesium + sodium + potassium) and acid anions (sulfate + chloride + nitrate). A bias similar to the historical/pre-2009 ion imbalance also exists for the 2009 ANC comparison (Figure 4). The calculated value on average is 5.9 $\mu Eq\ L^{-1}$ greater than the measured value (compared to 7.8 $\mu Eq\ L^{-1}$ greater in 2008, 7.5 $\mu Eq\ L^{-1}$ greater in 2007, 11.6 $\mu Eq\ L^{-1}$ greater in 2006, 15.8 $\mu Eq\ L^{-1}$ greater in 2005, 15.65 $\mu Eq\ L^{-1}$ greater in 2004 and 7.55 $\mu Eq\ L^{-1}$ greater in 2003), with 86% of the individual samples having greater calculated than measured ANC. Although no single sample, or a small number of samples, appears to dominate the bias; a shift from the 1:1 line in Figure 4 is evident for most samples. One-quarter of the non-blank 2009 samples had calculated minus measured ANCs > 10 $\mu Eq\ L^{-1}$ (compared to 33% in 2008, 31% in 2007, 43% in 2006, 54% in 2005, 80% in 2004 and 27% in 2003). Eilers et al. (1998) label samples having calculated minus measured ANCs > 5 $\mu Eq\ L^{-1}$ as "outliers". By this definition 64% of the 2009 samples would be "outliers" (compared to 75% in 2008, 59% in 2007, 42% in 2006, 79% in 2005 and over 92% in 2004). Although the imbalance between calculated and measured ANC is further evidence that either one or more constituents aren't being analyzed--or there are laboratory problems--by this measure the 2009 sample analysis is generally of higher quality than analyses from most of the prior years.

5.1.1.5 Theoretical versus Measured Conductivity

The measured versus theoretical conductivities from the 2009 lake samples show most samples (over 92%) to be within the +/-1 µS cm^{-1} criterion used by Eilers et al. (1998) to identify “outlier” values (Figure 5). The 92% value is better than the average for several prior years (93% in 2008, 96% in 2007, 86% in 2005 and 2006, and 88% in three other prior years). In a broader comparison, less than 70% of the 1985 Western Lake Survey samples from Sierran lakes were within the +/-1 µS cm^{-1} criterion.

Figure 4. Calculated versus Measured ANC--2009 Non-blank Samples

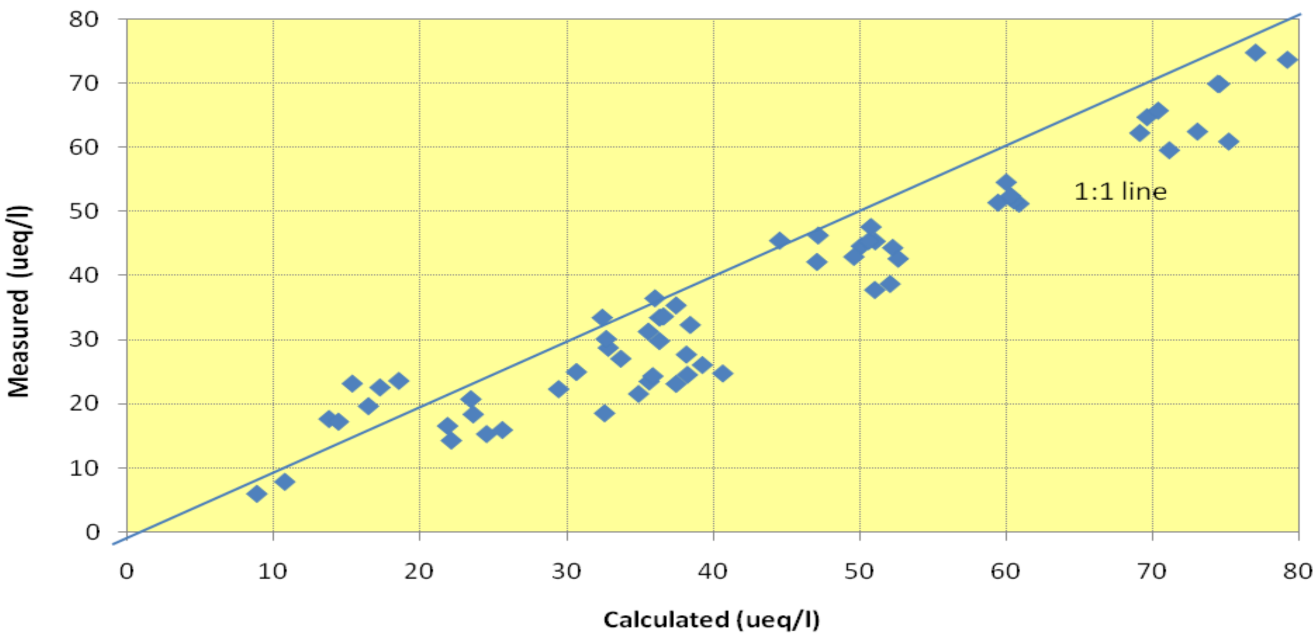
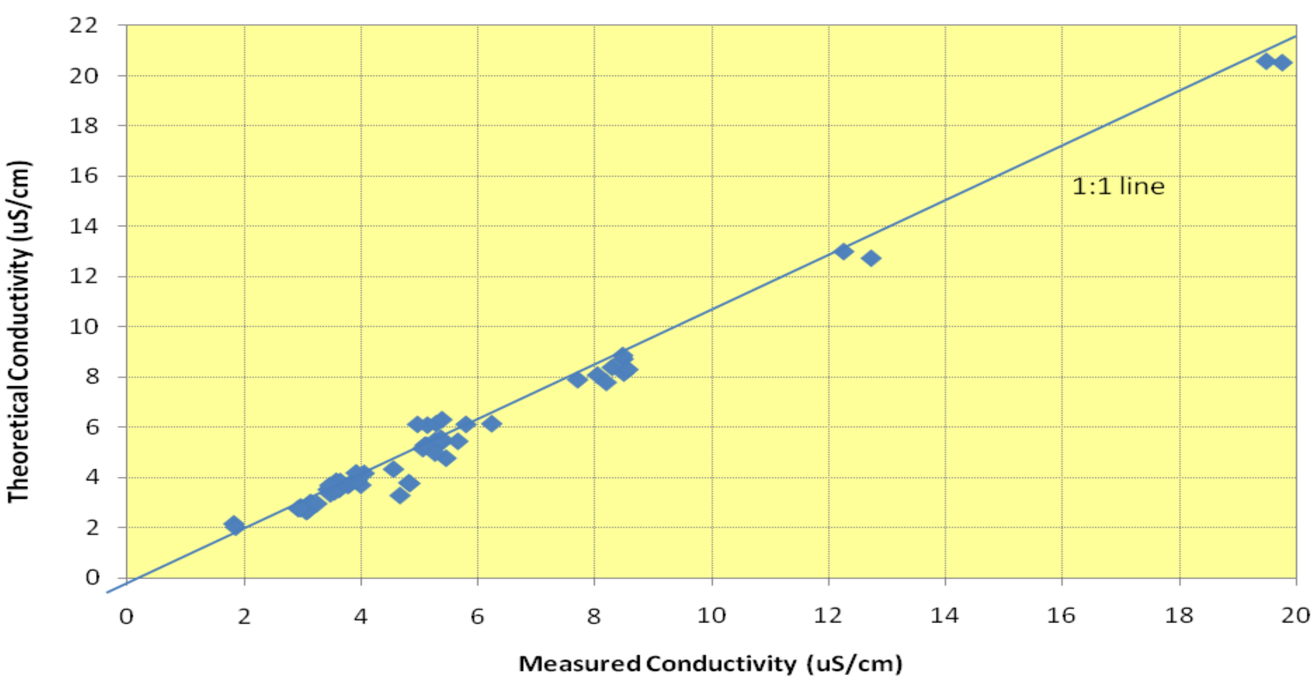


Figure 5. Theoretical versus Measured Conductivity--2009 Non-blank Samples



Five samples collected in 2009—epilimnion duplicates from Little East Marie Lake, an epilimnion sample from Mokelumne 14 Lake, and shoreline samples from Cascade and Dana Lakes--exceeded Eilers et al.'s +/- 1 $\mu S\ cm^{-1}$ criteria. The criterion value for all five samples was close to the threshold, 1.4, 1.2, 1.1, 1.1 and 1.0 $\mu S\ cm^{-1}$, suggesting little cause for concern. Also, 2008 samples from these lakes did not cross the Eilers et al. threshold suggesting that there's no longer term issue with sample collection or analysis from these lakes.

If there was no bias 50% of the samples would have measured conductivity greater than calculated conductivity (or vice versa). Per this metric there is some bias in the 2009 samples—41% of the non-blank samples have greater measured than calculated conductivity (compared to 26% in 2008, 50% in 2007, over 70% in 2006, 89% in 2005, 80% in 2004 and 75% in 2003)—although the mean bias is small, 0.05 $\mu S\ cm^{-1}$. The 2009 41% value is better than most years in that it is closer to the "no bias" 50% value. Eilers (2003) described Gallatin National Forest lake samples with approximately this amount of bias as not presenting "… a significant concern with respect to the quality of the data".

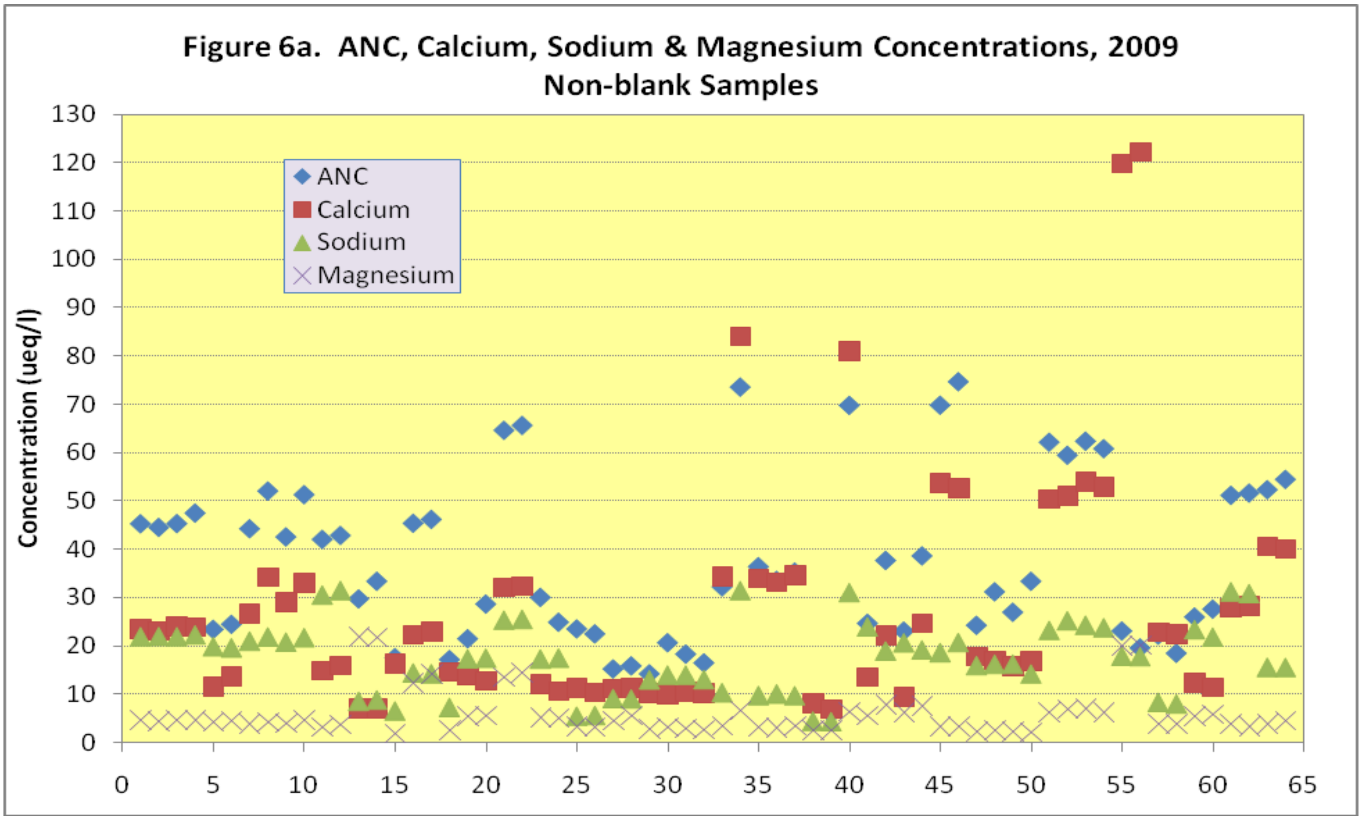
5.1.1.6 Outliers

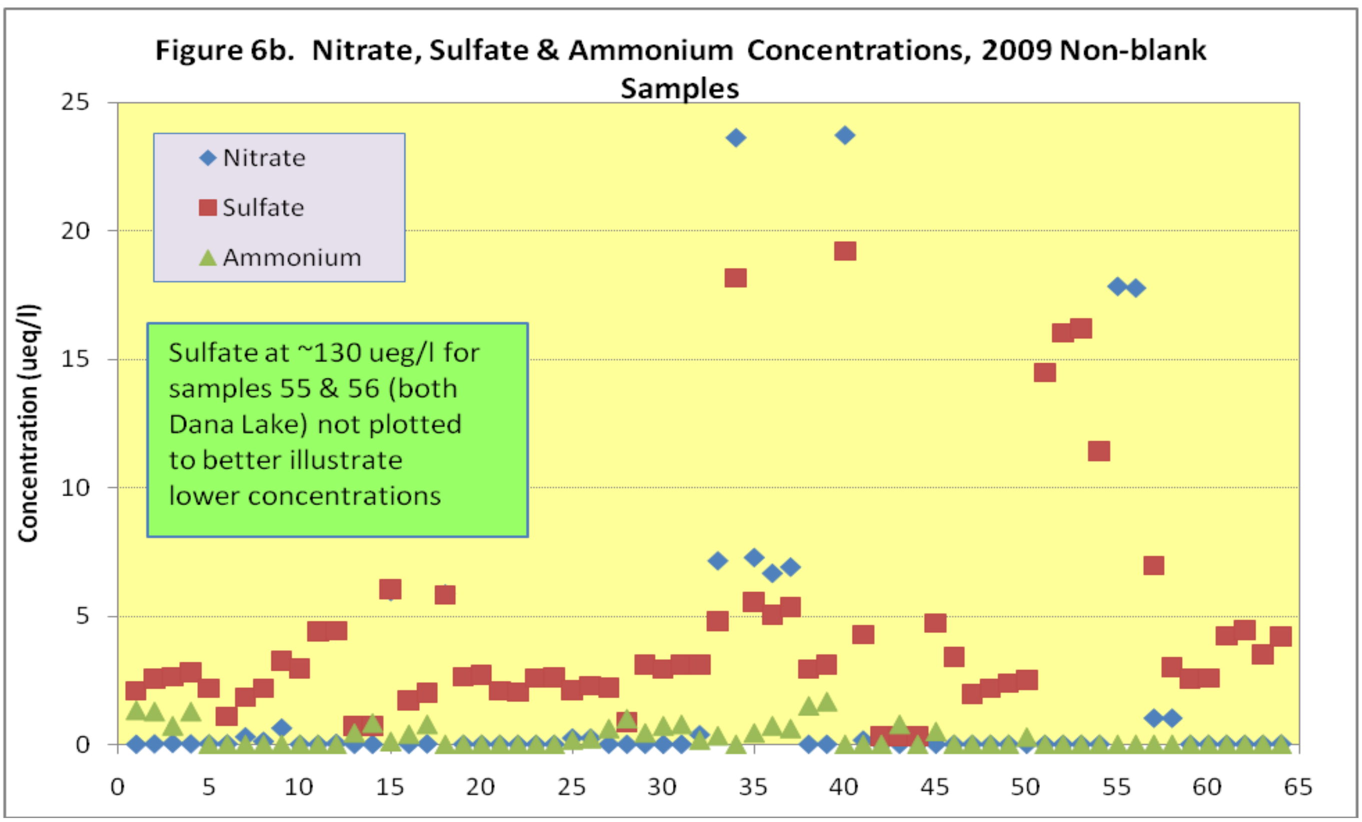
Outliers are extreme values that are inexplicable. Contamination by body contact with sample liquid, for instance, is typically identified by outlier values of sodium and chloride. For all 2009 non-blank samples, concentrations of calcium, sodium, magnesium, ANC, chloride, nitrate and sulfate are plotted in Figure 6. Outliers are assessed visually and statistically using Dixon's outlier test.

5.1.1.6.1 Visual assessment

The pair of duplicate samples from the epilimnion at Dana Lake had particularly high concentrations of calcium and sulfate in the 2009 sampling (Figures 6a and b—samples 55-56). In addition, the Dana duplicates had the second highest nitrate concentrations of any lake (Figure 6b). The pair of duplicate epilimnion samples from Bench Lake had the highest nitrate concentrations in 2009. There is historical precedent for these high concentrations at both lakes; each year that Dana has been sampled high concentrations of sulfate and nitrate in particular have been found, with Dana having the highest sulfate and nitrate of any lake sampled each year. These high concentrations are not considered to be a problem. Reasons for these high concentrations have been addressed in earlier annual reports, and have been speculatively attributed to geological influences and atmospheric transport from east of the Sierra Nevada. See also section 5.2.13 for more specifics on the geology of the Dana Lake basin.

To put the "high" concentrations into further perspective, some lakes sampled in the 1985 Western Lake Survey (Landers et al. 1987) had high calcium and sulfate concentrations (e.g., Hoover Lake in Hoover Wilderness, with sulfate = 386 $\mu Eq\ L^{-1}$ and calcium = 493 $\mu Eq\ L^{-1}$), much higher than the Dana Lake concentrations. And lakes outside of the Sierra commonly have higher concentrations. For instance, the mean calcium and ANC concentrations of 1,798 lakes surveyed in the Eastern Lake Survey were 245 and 264 $\mu Eq\ L^{-1}$ respectively (Kanciruk et al. 1986).





5.1.1.6.2 Statistical assessment

Dixon's outlier test (Dixon 1953, NIC 2005) assumes data are distributed normally or log normally and tests whether a suspect value fits the distribution of the rest of the data set. At the 0.05 level of statistical significance, Dixon's test identified no outliers for calcium, chloride, potassium, magnesium, sodium, ammonium, nitrate, or pH at any lake. However, both duplicate shoreline samples at Dana Lake in Ansel Adams Wilderness were identified as statistical outliers for sulfate and conductivity, as were both Key Lake shoreline samples for ANC. Sulfate concentrations at Dana have ranged from nearly 60 to 130 μEq L^{-1} during each monitoring year from 2004 to 2009 period, implying that the 2009 high sulfate concentrations are not atypical. These values are much higher than the median sulfate concentration in 2009 (for all samples) of 8.1 μEq L^{-1}, implying that significantly high sulfate at Dana Lake is to be expected in the Dixon outlier test. Similarly, conductivity at Dana has always been relatively high, and the 2009 conductivity at Dana of 19.6 uS/cm compares to a mean of 5.5 for all 2009 samples. Last, ANCs at Key Lake have also always been relatively low, and the 2009 concentrations of the two shoreline duplicates are higher than from samples collected in 2004 and 2005.

For these reasons it does not appear that either the ANC, conductivity or the sulfate concentrations from Key and Dana Lakes in 2009 are problematic, and these values are retained in the dataset.

5.1.2 Precision -- Duplicate Samples

Thirty-two"duplicate" pairs of samples were collected in 2009 from shallow mid-lake locations (16 lakes), at lake outlets or along the shoreline (13 lakes), and three pairs from the hypolimnion. Most of the duplicates were collected about 5 minutes apart. These duplicates should be nearly identical in their constituent concentrations. A measure of chemical variation, the percent relative standard deviation (%RSD), was calculated for all duplicates for ANC, calcium, nitrate, conductivity, magnesium, sodium, chloride, potassium and sulfate concentrations. Per B. Gauthier (5/30/02 email to J. Peterson) the %RSD for duplicate samples should be less than or equal to 10%. For each constituent the following table lists the percentage of the pairs of duplicate samples with %RSD greater than 10% for samples collected between 2001 and 2009:

	2009	2008	2007	2006	2005	2004	2003	2002	2001
Number of Duplicate Pairs	32	34	45	18	9	7	13	11	12
Chemical Constituent									
ANC	25	24	33	33	44	57	31	55	8
Calcium	9	6	22	0	11	14	31	36	25
Nitrate	47	33	79	65	0	29	8	0	9
Conductivity	0	0	0	0	22	0	8	18	17
Magnesium	13	12	44	0	11	29	39	36	8
Sodium	3	6	7	0	22	14	8	9	8
Potassium	31	32	38	22	22	57	8	18	8
Chloride	25	32	47	28	56	29	23	27	17
Sulfate	34	12	18	17	22	0	23	18	25

For the %RSD metric—

- Compared to earlier years the 2009 duplicate samples ranked about "average" compared to the %RSDs for the group of prior years.
- Many constituents have %RSD values above the 10% criteria for some years, implying a fair amount of "noise" in the laboratory analyses, the sample collection, handling and transport procedures, or some combination of all three activities.

The %RSD calculation procedure is sensitive to "sample size". Calculation of standard deviations on the basis of two values is marginal; typically at least three values are used, and ideally a much larger sample size should be the basis for the %RSD calculation. The relatively high values listed in the table above for some years may be partially due to this sample size effect.

Another reason for some relatively high %RSD values, particularly for nitrate, may be low concentrations, near or below the detection limit. For instance, the concentrations of the two nitrate duplicates from hypolimnion samples taken from East Chain Lk in 2008 were both low, 0.06 and 0.35 μEq L^{-1}. Nevertheless the %RSD for these duplicates is 98%, much

greater than the 10% threshold value. Also the 2009 median differences in nitrate, ammonium, potassium, sodium and calcium are below 0.05 µEq L^{-1}, a very low magnitude. These low median differences suggest that although the 2009 %RSD values for some duplicates are high, the absolute value of the differences is generally small.

ANC is the single best constituent for %RSD assessment because it tends to integrate the concentrations of several of the other constituents. ANC is also the single best correlate with potential acidification. The eight largest ANC %RSD values in 2009 ranged from 10 to 20. Similarly in 2008 the larger ANCs had a relatively narrow range. In contrast in 2007 Bullfrog Lake's epilimnion %RSD was 40, almost twice that of the second greatest ANC %RSD from 2007. The 2009 lakes with relatively high (10-20) %RSD often had low ANCs and the absolute difference in the ANCs were relatively small (e.g., 19.6 and 23.1 µEq $L^{-1}$from shoreline samples at Dana Lk). The small absolute ANC difference is promising and suggests that the laboratory and field sample collection procedures are of high quality.

None of the %RSD values for sodium were above 20 & most of the %RSDs for ANC, hydrogen, magnesium, and potassium were under 15. As in prior years, several duplicates for ammonium, chloride, nitrate, and sulfate had %RSDs above 20. High %RSDs for nitrate, sulfate, and ammonium may be explained by low absolute values—e.g., 0.0 and 0.016 nitrate µEq L^{-1} for the two Hufford Lk shoreline samples--where even a small absolute difference between duplicates can produce a relatively large percent difference.

Seven of the 2009 duplicate pairs had at least four constituents with %RSD values greater than 10. This is up from two sets of dups in 2008. At the extreme, at Mokelumne 14 eight of eleven constituents had %RSD greater than 10. In 2008 Mokelumne 14 did not have nearly as many high %RSD constituents. In 2009 Mokelumne 14 also had the highest %RSD values for sulfate and calcium of any lake. These results suggest a possible problem at Mokelumne 14. If similar results occur in 2010, a closer look at field procedures at Mokelumne 14 may be warranted.

The mean absolute differences between the duplicates (the precision) for major chemical constituents are compared below for years 2003 through 2009.

Constituent	**Unit**		**Mean Absolute Difference**					
		2009	2008	2007	2006	2005	2004	2003
ANC	µEq L^{-1}	2.50	2.83	3.36	4.33	3.62	2.35	3.18
Conductivity	µS cm^{-1}	0.17	0.13	0.34	0.30	1.36	0.49	0.22
Calcium	µEq L^{-1}	1.14	1.35	2.48	0.85	1.08	1.34	1.91
Magnesium	µEq L^{-1}	0.36	0.53	0.84	0.30	0.29	0.80	0.72
Sodium	µEq L^{-1}	0.57	0.61	0.65	0.29	1.12	2.70	0.72
Potassium	µEq L^{-1}	0.42	0.56	0.50	0.26	8.81	1.91	0.34
Chloride	µEq L^{-1}	0.27	0.36	0.53	0.17	7.94	0.16	0.62
Sulfate	µEq L^{-1}	0.83	0.13	1.22	0.89	0.20	0.33	0.24
Nitrate	µEq L^{-1}	0.07	0.16	0.20	0.20	0.03	0.25	0.09

Compared to the earlier years, the 2009 results are lower than average for most constituents. In a study of lake waters on the Mt. Baker-Snoqualmie National Forest in Washington, Eilers et al. (1998) characterized samples with mean absolute differences $\leq$ 1.0 µEq L^{-1} as dilute waters. Except for ANC and calcium, the 2009 Sierran samples match this criterion for dilute lake water.

On the basis of the 2009 %RSD analysis there is no obvious reason to suggest a problem(s) with either any particular lake samples—except possibly Mokelumne 14--or the broader sample collection and analysis procedures.

5.1.3 Bias -- Field Blanks

To help assure that water collection bottles are not contaminating samples, "field blanks" have water—typically de-ionized with very low or undetectable constituent concentrations—that is stored in the bottles for time periods comparable to the amount of time sample water remains in a bottle prior to analysis. Field blanks are typically sent out by the laboratory with the other bottles and taken to the field along with the actual sample bottles. Common contaminants in the field blanks are sodium and chloride, from perspiration, or elevated acidity as a residue from prior cleaning of the bottle

with dilute acids. The QA/QC protocol for the chemistry laboratory at the Riverside unit of the Forest Service's Pacific Southwest Research Station states that "[T]he value of a blank reading should be less than ± 0.05 mg L^{-1} from zero". Eilers et al. (1998) used 1.0 μEq L^{-1} for individual cations as a trigger value for blank contamination and the FS national air program (USDA Forest Service 2007) states that ideally conductivity in blanks should be less than 2 uS/cm.

Seven field blanks were incorporated into the 2009 sample collections. Fifteen percent of 69 constituent analyses had detectable results, compared with 57% in 2008, 50% in 2007, 42% in 2006 and 33% in 2005. This, and other comparisons to prior years, is conditioned by changes in nitrate detection limit in 2009, to 0.03 mg/l, and in 2008, down to 0.007 mg/l, compared to 0.02 mg/l in prior years. No detectable concentrations of sodium or nitrate were identified in any 2009 sample, and only one of the seven samples had detectable magnesium and potassium.

Twenty percent of the blank cation concentrations were greater than Eilers et al's 1.0 μEq L^{-1}, with all calcium blanks near or above 1 μEq L^{-1}. Relatively high calcium concentrations in the blanks have been common from prior years as well. The only constituent with a concentration greater than PSW Station's ± 0.05 mg L^{-1} criterion was chloride from Lower Cole Ck Lake. Conductivity in the seven blanks ranged from 1.3 to 1.8 uS/cm, higher than 2008's 0.8 to 1.0 uS/cm range, and about on par with 2007's 1.2 to 1.9 uS/cm range. All conductivities were below the national air program's 2 uS/cm criterion.

In summary, the field blank assessment does not appear to identify a systematic problem with sample collection although relatively high calcium concentrations continue, as in most prior years. No individual blank samples were identified as problematic.

5.1.4 <u>Summary of Quality Control Findings</u>

The 2009 quality control analyses did not identify any new or unexpected issues, and for all QA/QC metrics the 2009 data are on par or better than in all prior years. The single most notable 2009 QA/QC result is continuation of a shift that began in 2008 away from persistent anion under-estimation through most prior years to an approximate equivalency of anion under-estimation to cation over-estimation.

5.2 Time Trends for Long-term Monitoring Lakes

Fourteen lakes have been monitored at least six times (see table on page 4), with one of these, Waca in Desolation Wilderness, sampled fourteen times since 1985. A monitoring duration of 5 or 6 years is minimal for preliminary assessment of temporal change, and the literature suggests that typically a much longer time period is needed before temporal trends can be statistically verified. To offer a preliminary assessment of temporal change, plots of the chemistry of the eleven lakes are presented in Figure 7, and the results of a trend analysis are presented.

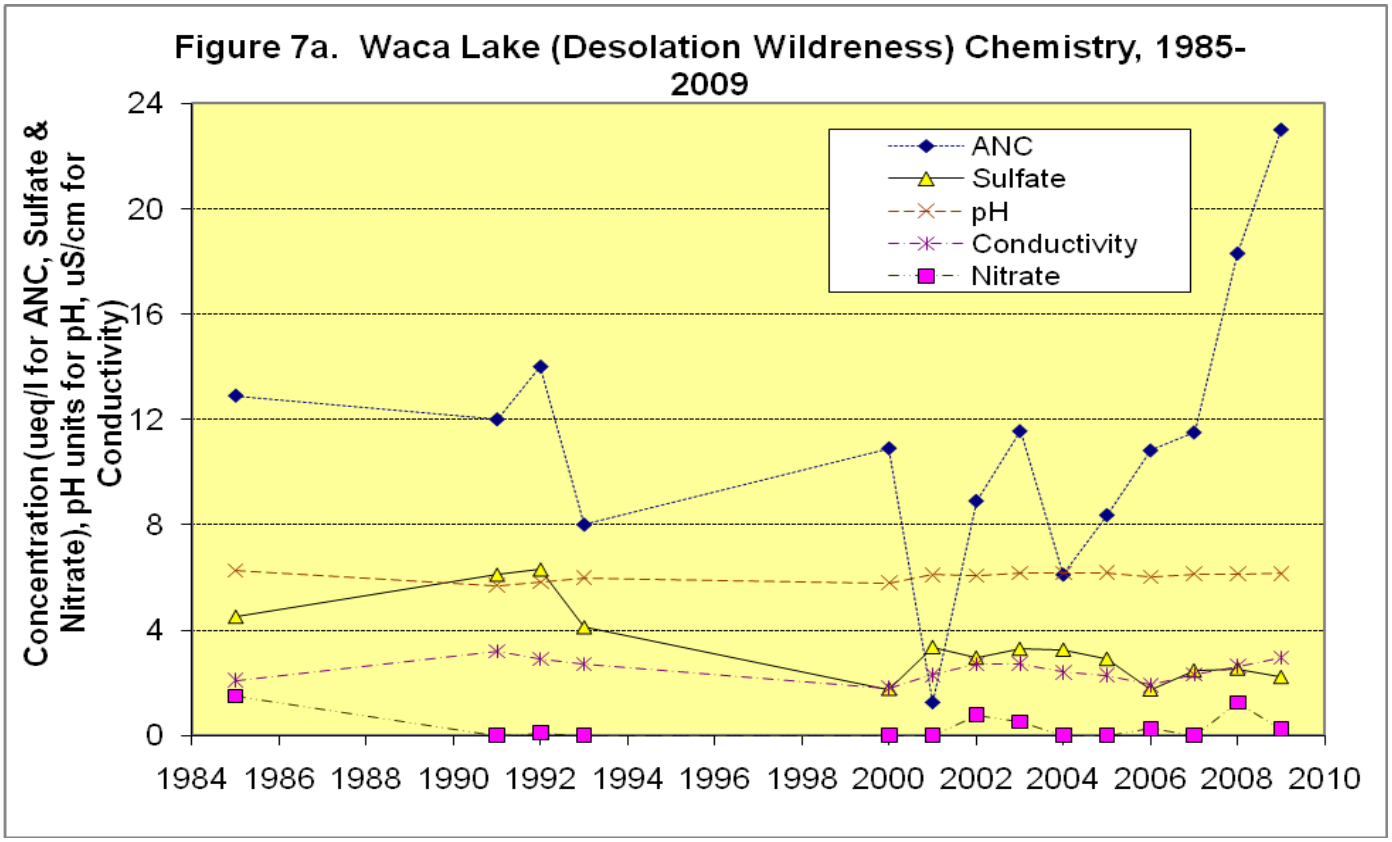


Figure 7a. Waca Lake (Desolation Wildreness) Chemistry, 1985-2009
Concentration (ueq/l for ANC, Sulfate & Nitrate), pH units for pH, uS/cm for Conductivity)
ANC
Sulfate
pH
Conductivity
Nitrate
0
4
8
12
16
20
24
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010

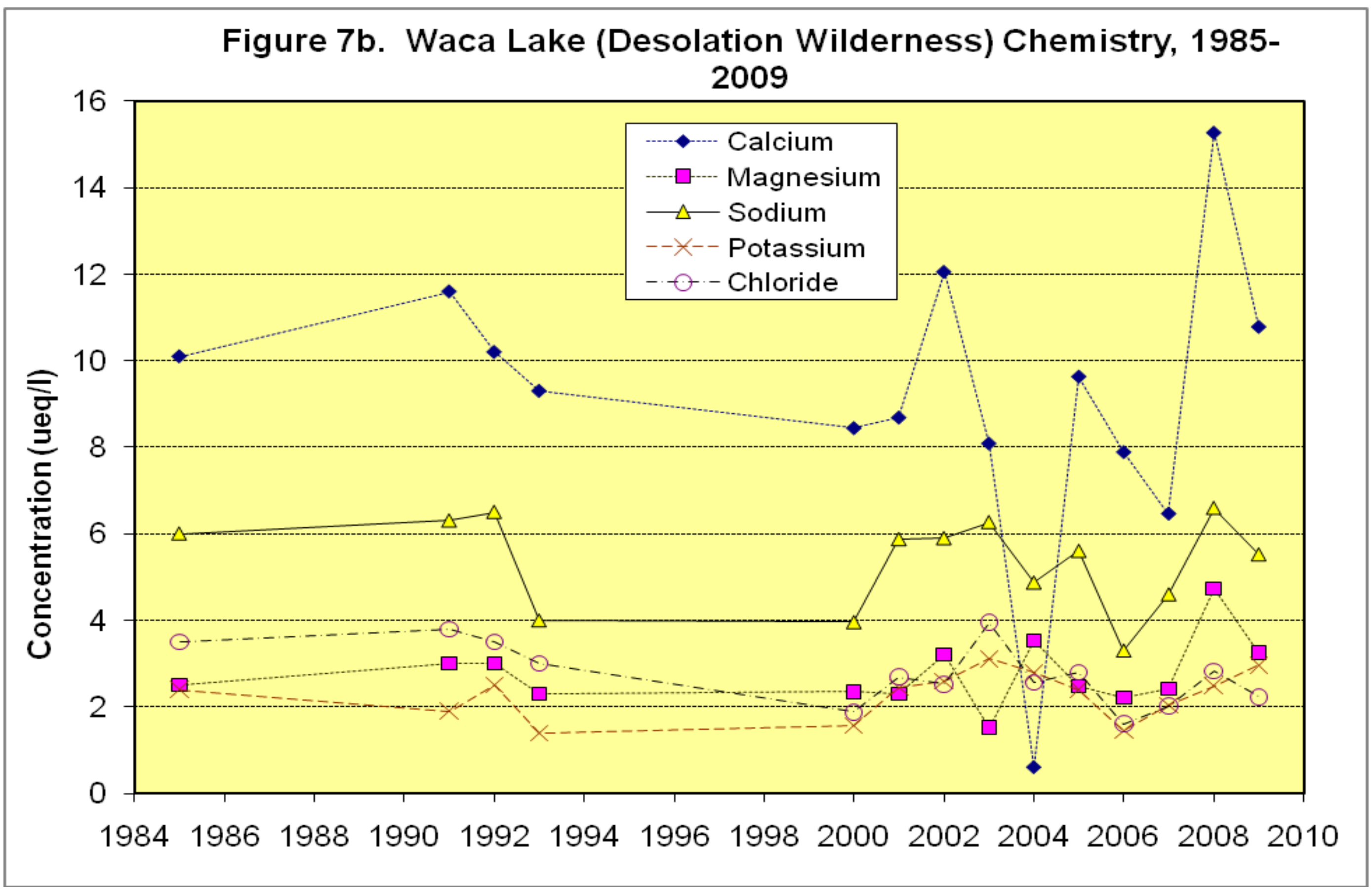


Figure 7b. Waca Lake (Desolation Wilderness) Chemistry, 1985-2009
Concentration (ueq/l)
Calcium
Magnesium
Sodium
Potassium
Chloride
0
2
4
6
8
10
12
14
16
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010

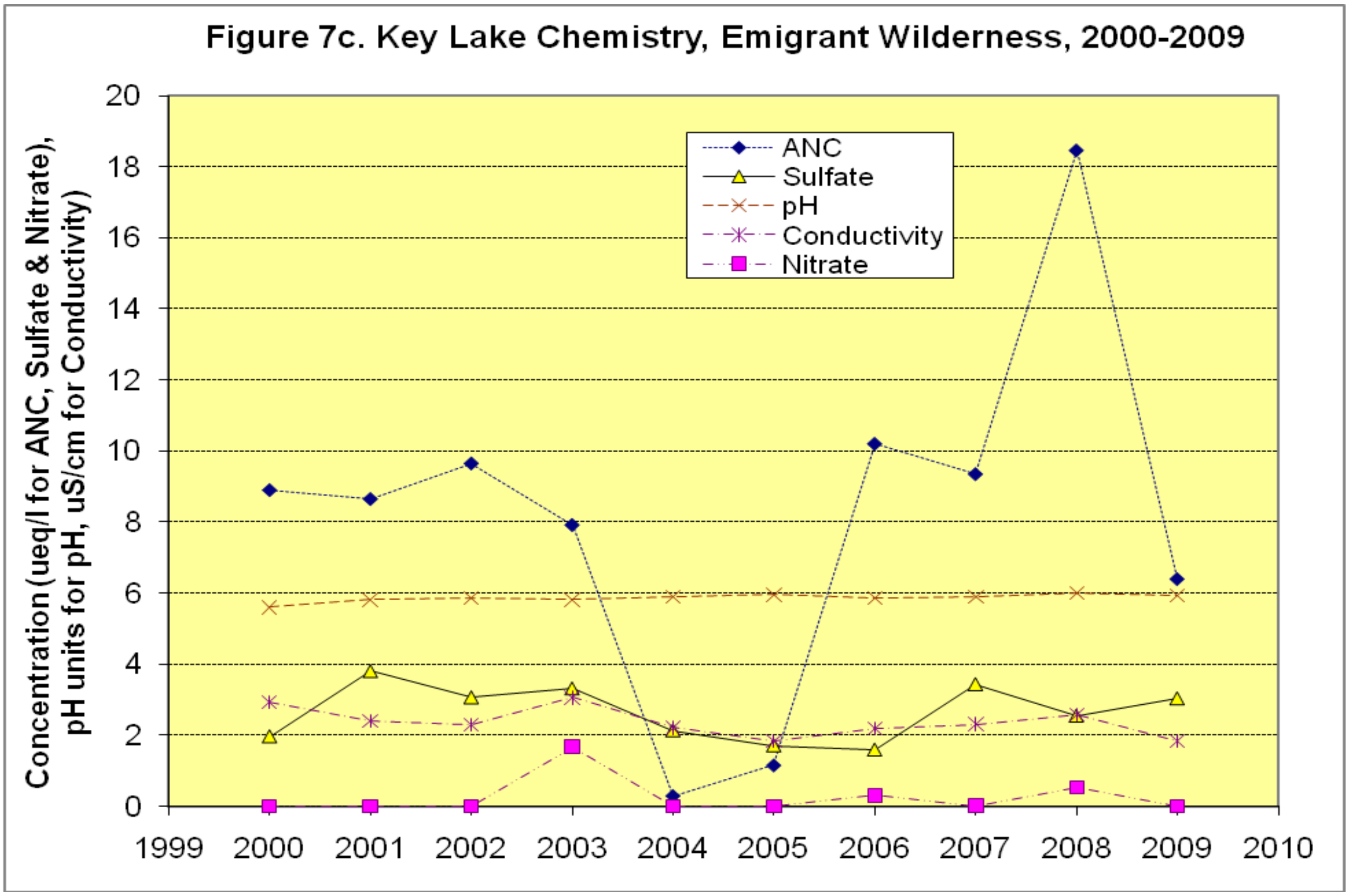


Figure 7c. Key Lake Chemistry, Emigrant Wilderness, 2000-2009
Concentration (ueq/l for ANC, Sulfate & Nitrate), pH units for pH, uS/cm for Conductivity)
ANC
Sulfate
pH
Conductivity
Nitrate
0
2
4
6
8
10
12
14
16
18
20
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

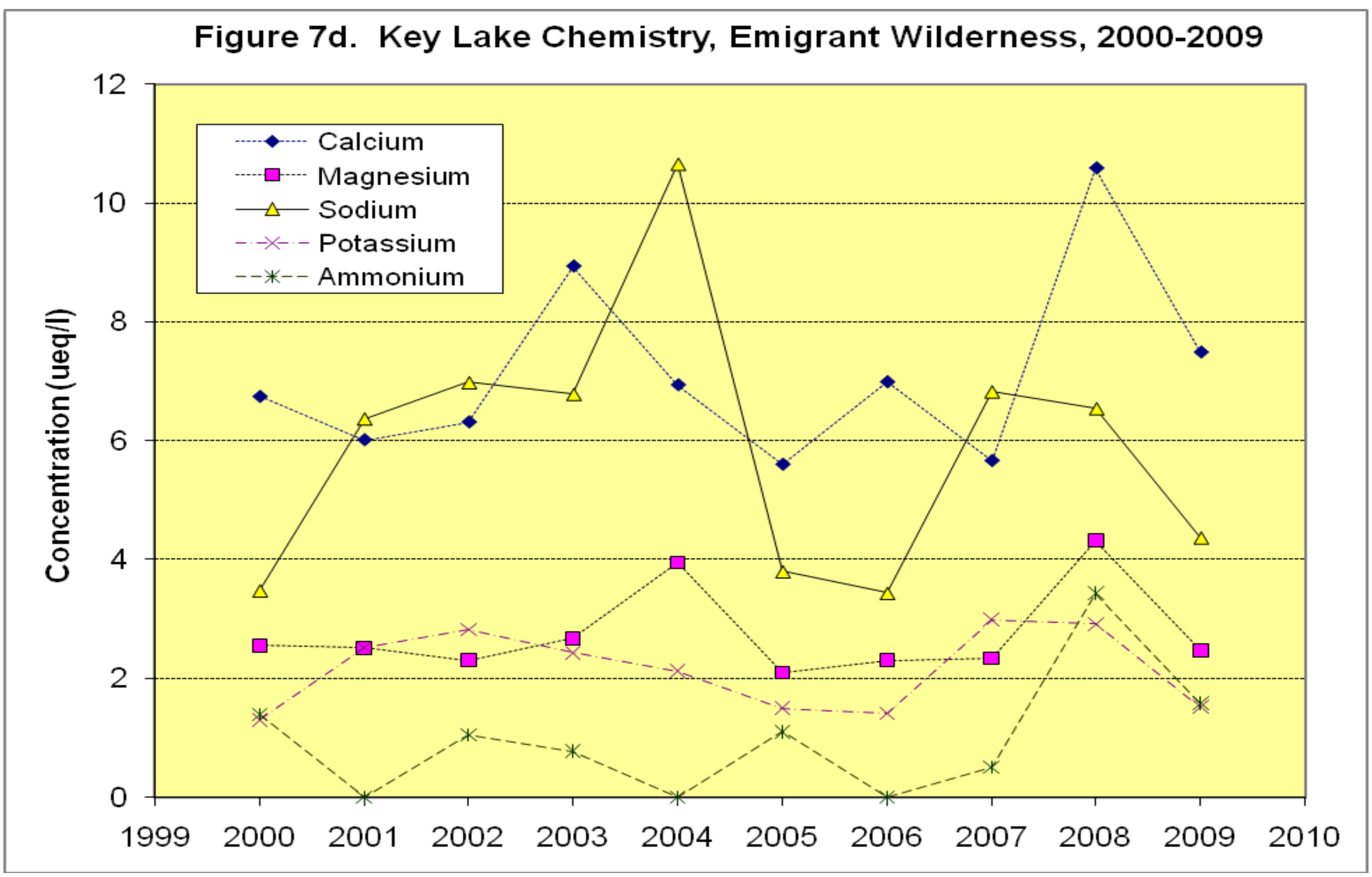


Figure 7d. Key Lake Chemistry, Emigrant Wilderness, 2000-2009
Concentration (ueq/l)
Calcium
Magnesium
Sodium
Potassium
Ammonium
0
2
4
6
8
10
12
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

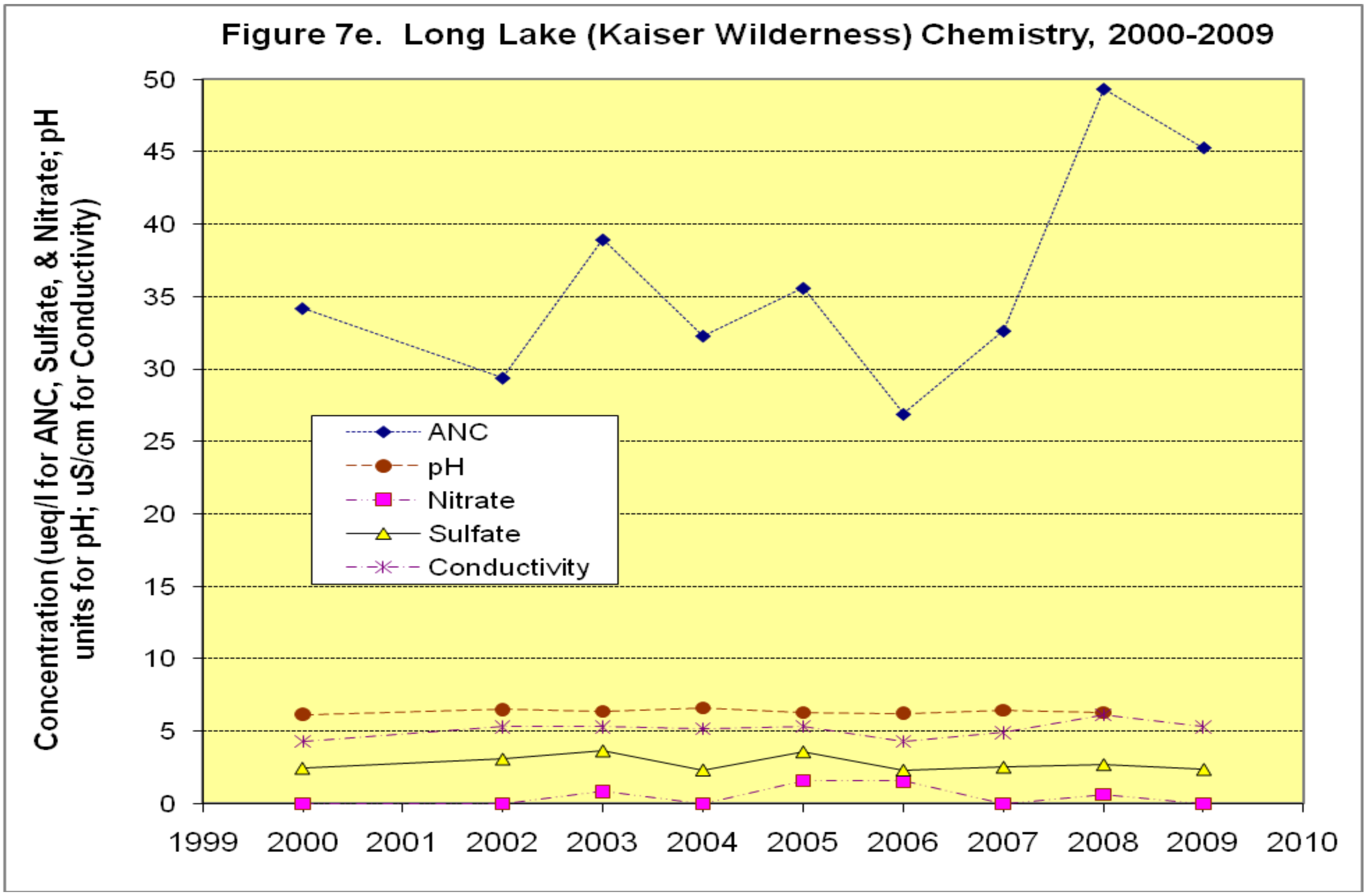


Figure 7e. Long Lake (Kaiser Wilderness) Chemistry, 2000-2009
Concentration (ueq/l for ANC, Sulfate, & Nitrate; pH units for pH; uS/cm for Conductivity)
ANC
pH
Nitrate
Sulfate
Conductivity
0
5
10
15
20
25
30
35
40
45
50
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

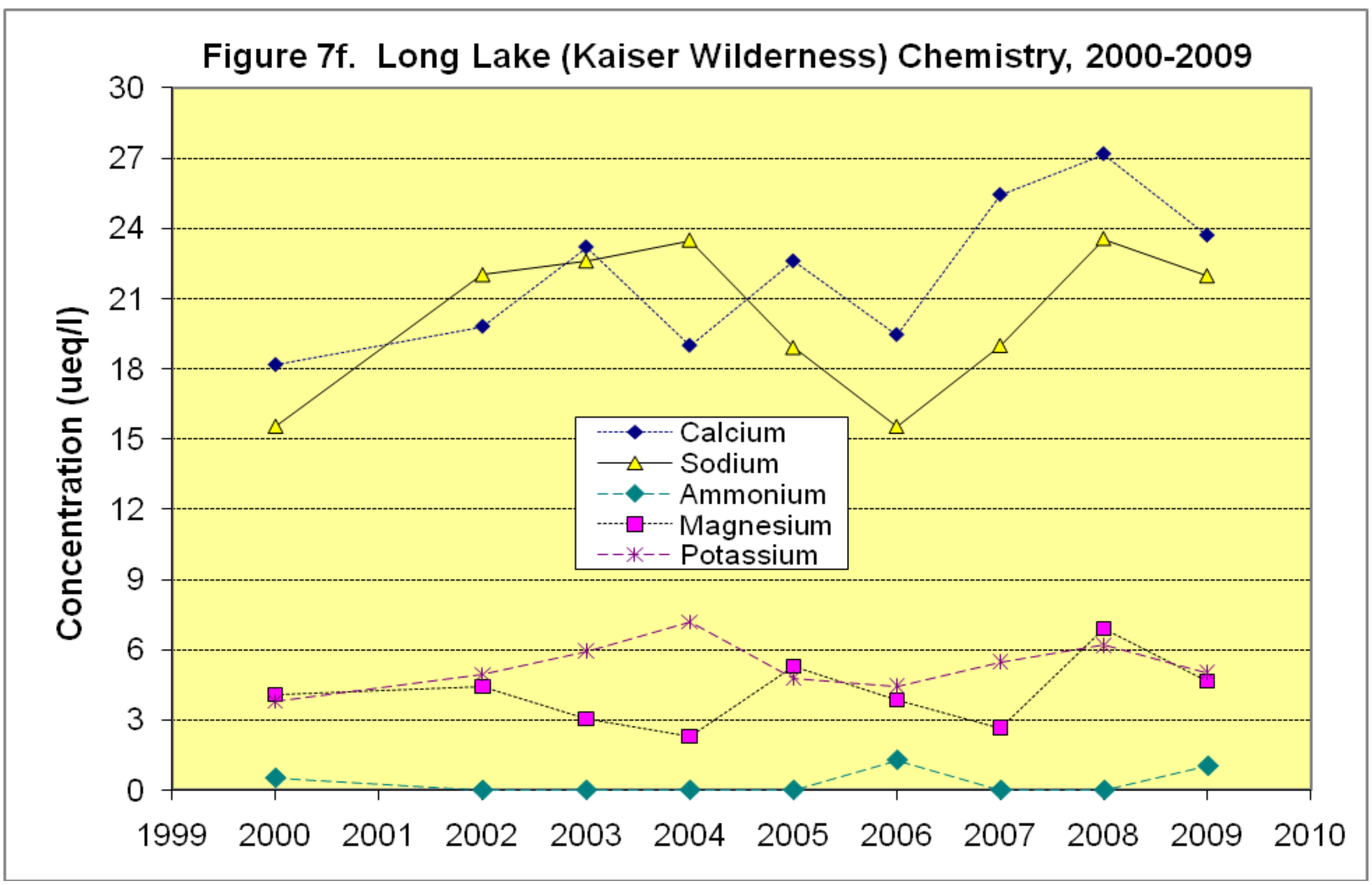


Figure 7f. Long Lake (Kaiser Wilderness) Chemistry, 2000-2009
Concentration (ueq/l)
Calcium
Sodium
Ammonium
Magnesium
Potassium
0
3
6
9
12
15
18
21
24
27
30
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

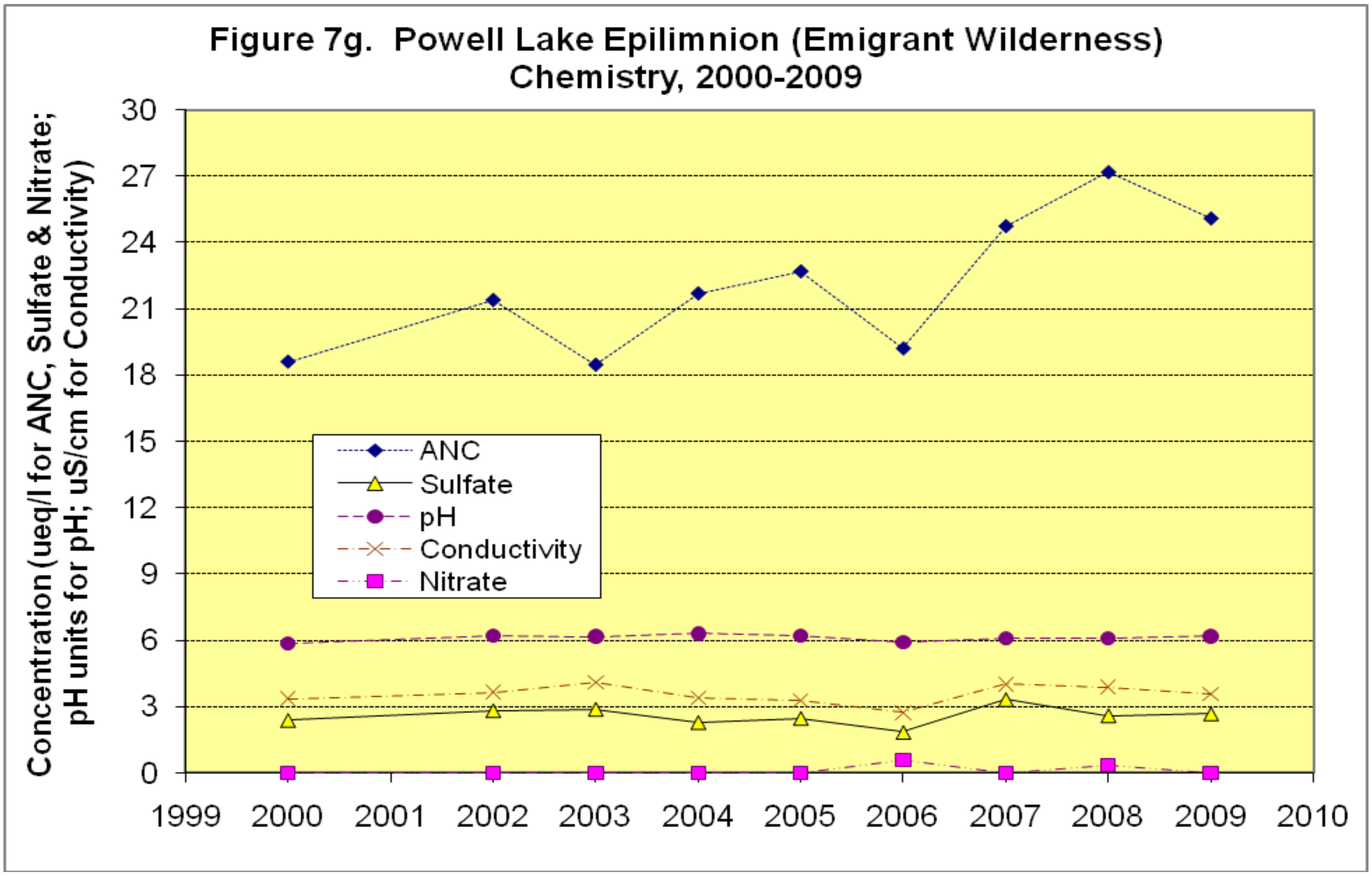


Figure 7g. Powell Lake Epilimnion (Emigrant Wilderness) Chemistry, 2000-2009
Concentration (ueq/l for ANC, Sulfate & Nitrate; pH units for pH; uS/cm for Conductivity)
0
3
6
9
12
15
18
21
24
27
30
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
ANC
Sulfate
pH
Conductivity
Nitrate

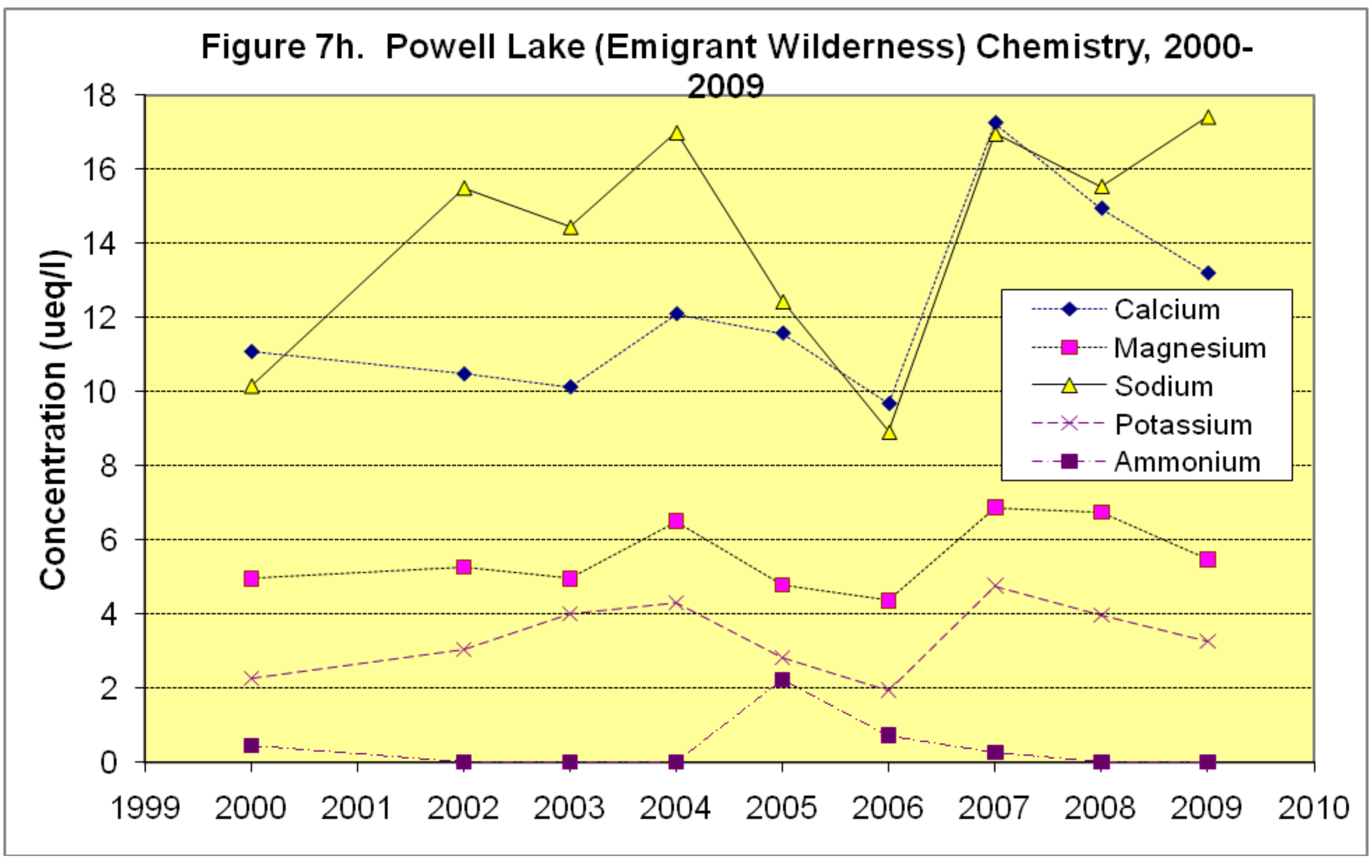


Figure 7h. Powell Lake (Emigrant Wilderness) Chemistry, 2000-2009
Concentration (ueq/l)
0
2
4
6
8
10
12
14
16
18
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Calcium
Magnesium
Sodium
Potassium
Ammonium

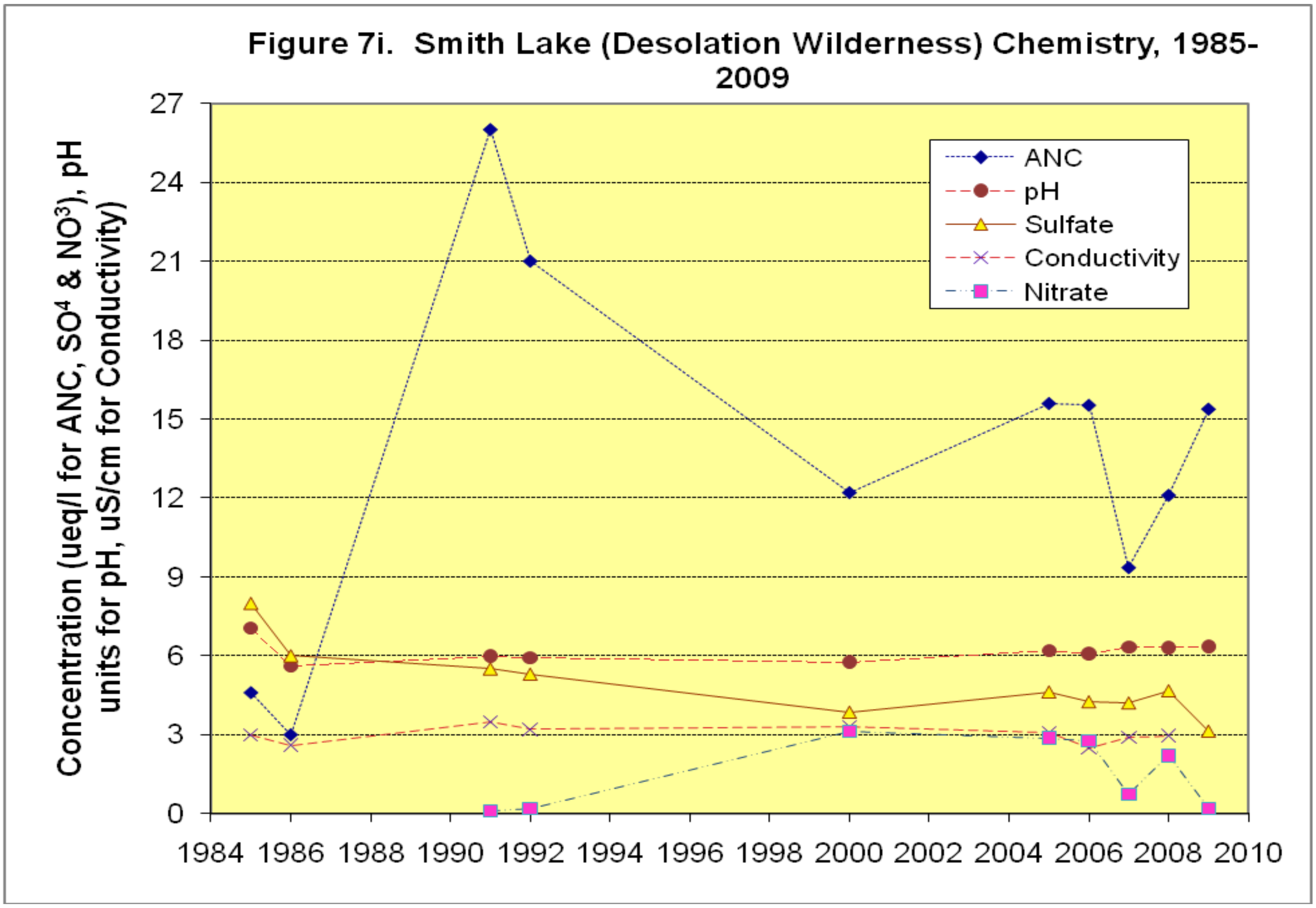


Figure 7i. Smith Lake (Desolation Wilderness) Chemistry, 1985-2009
Concentration (ueq/l for ANC, SO4 & NO3), pH units for pH, uS/cm for Conductivity)
ANC
pH
Sulfate
Conductivity
Nitrate
0
3
6
9
12
15
18
21
24
27
1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010

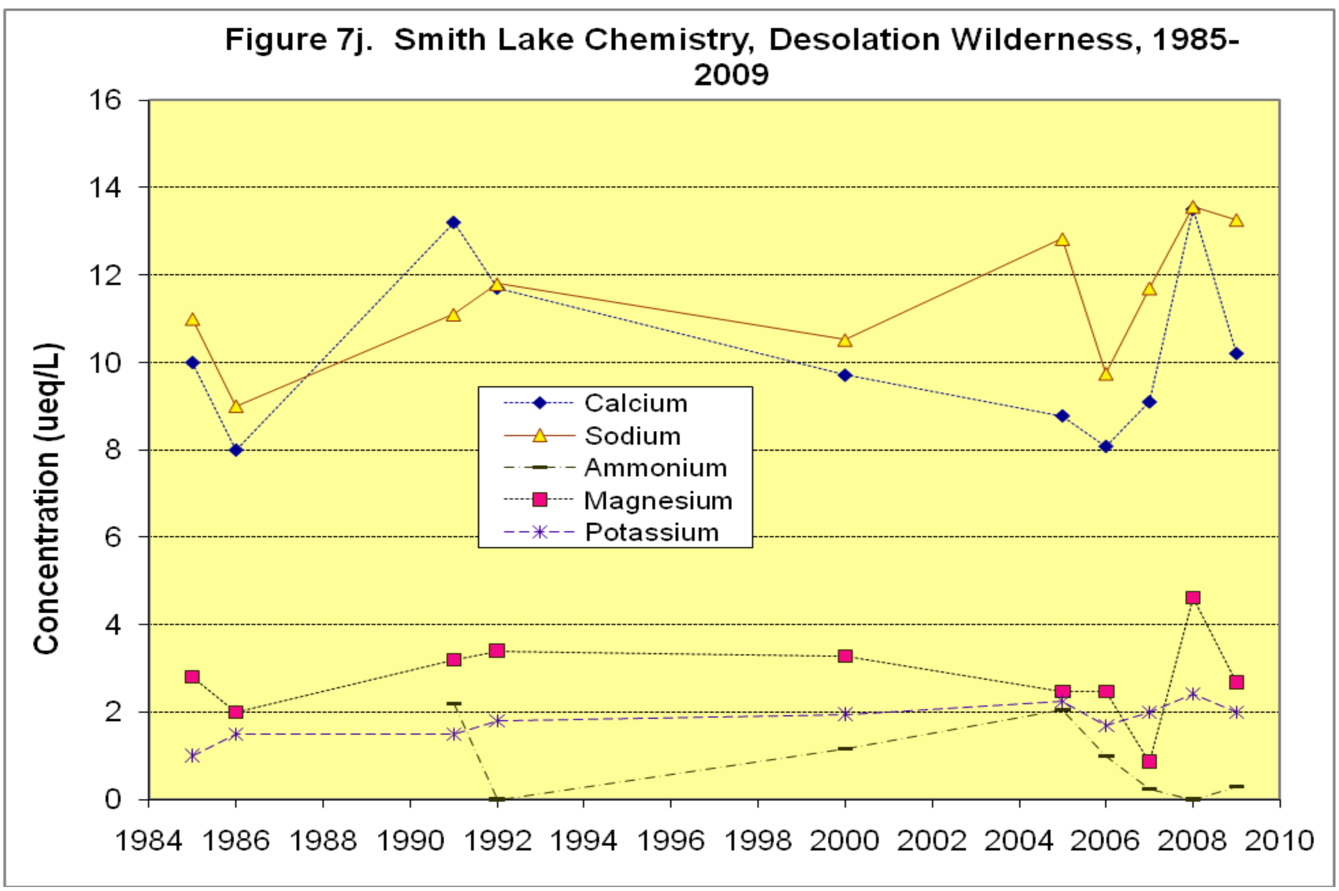


Figure 7j. Smith Lake Chemistry, Desolation Wilderness, 1985-2009
Concentration (ueq/L)
Calcium
Sodium
Ammonium
Magnesium
Potassium
0
2
4
6
8
10
12
14
16
1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010

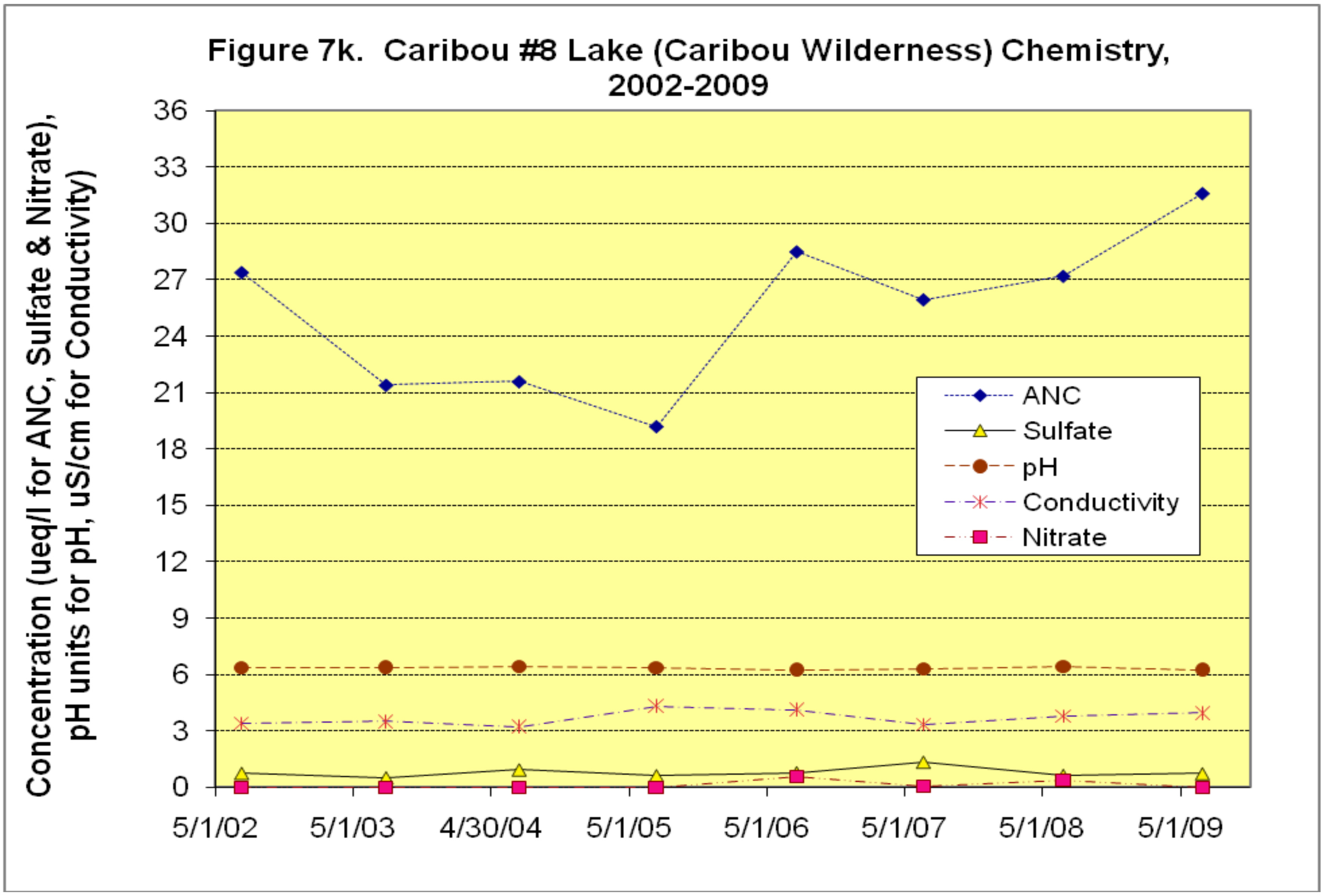


Figure 7k. Caribou #8 Lake (Caribou Wilderness) Chemistry, 2002-2009
Concentration (ueq/l for ANC, Sulfate & Nitrate), pH units for pH, uS/cm for Conductivity)
36
33
30
27
24
21
18
15
12
9
6
3
0
5/1/02
5/1/03
4/30/04
5/1/05
5/1/06
5/1/07
5/1/08
5/1/09
ANC
Sulfate
pH
Conductivity
Nitrate

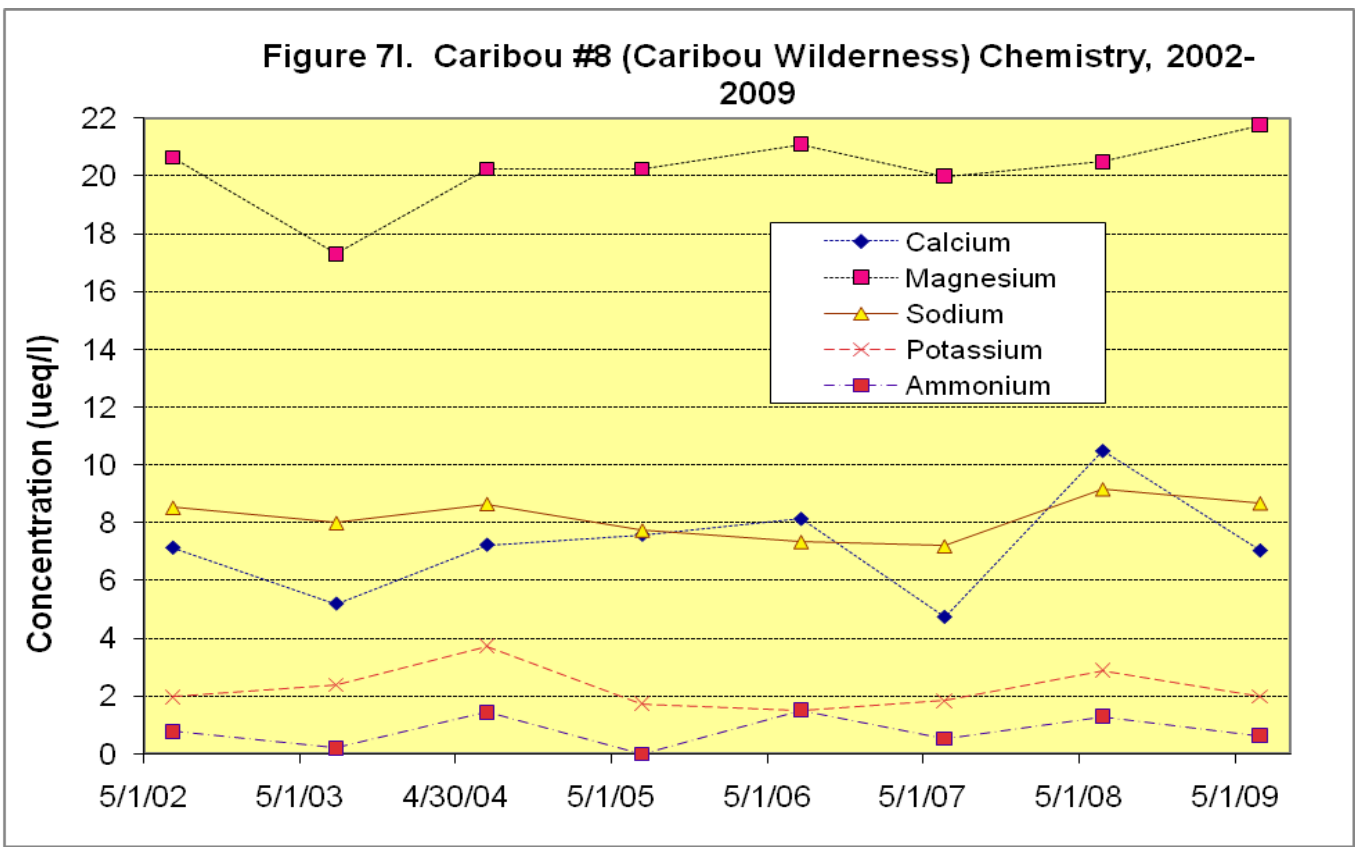


Figure 7l. Caribou #8 (Caribou Wilderness) Chemistry, 2002-2009
Concentration (ueq/l)
22
20
18
16
14
12
10
8
6
4
2
0
5/1/02
5/1/03
4/30/04
5/1/05
5/1/06
5/1/07
5/1/08
5/1/09
Calcium
Magnesium
Sodium
Potassium
Ammonium

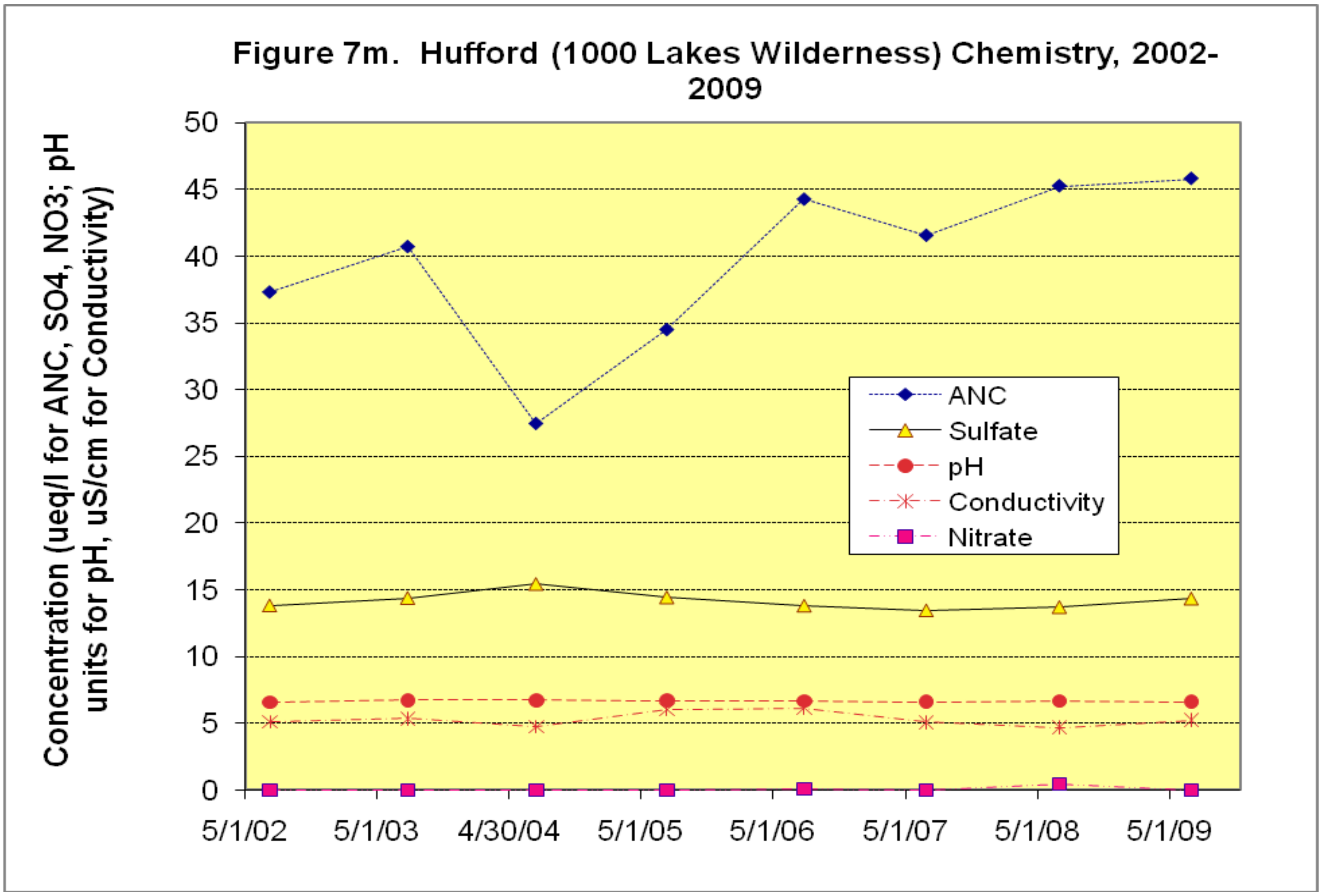


Figure 7m. Hufford (1000 Lakes Wilderness) Chemistry, 2002-2009
Concentration (ueq/l for ANC, SO4, NO3; pH units for pH, uS/cm for Conductivity)
ANC
Sulfate
pH
Conductivity
Nitrate
5/1/02
5/1/03
4/30/04
5/1/05
5/1/06
5/1/07
5/1/08
5/1/09

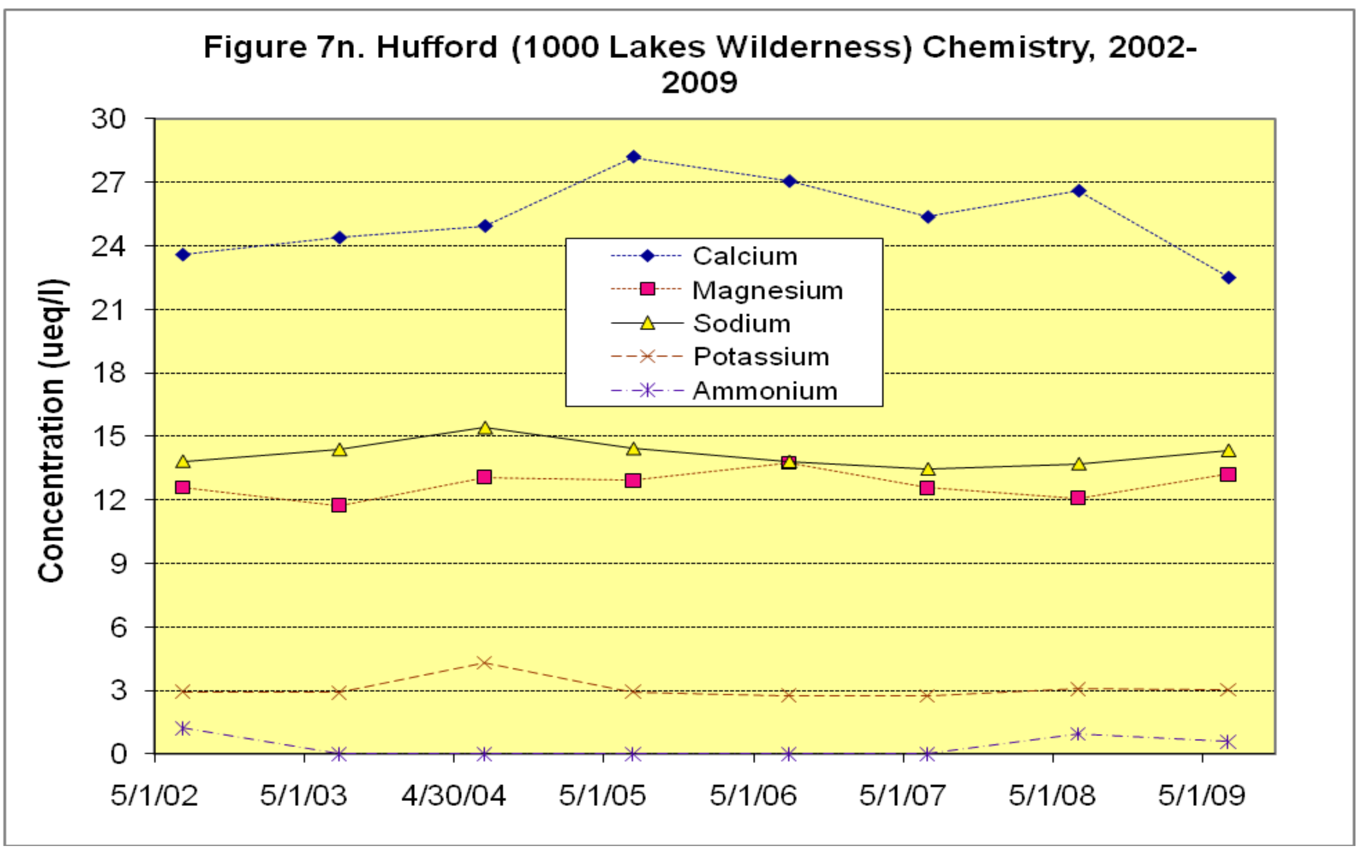


Figure 7n. Hufford (1000 Lakes Wilderness) Chemistry, 2002-2009
Concentration (ueq/l)
Calcium
Magnesium
Sodium
Potassium
Ammonium
5/1/02
5/1/03
4/30/04
5/1/05
5/1/06
5/1/07
5/1/08
5/1/09

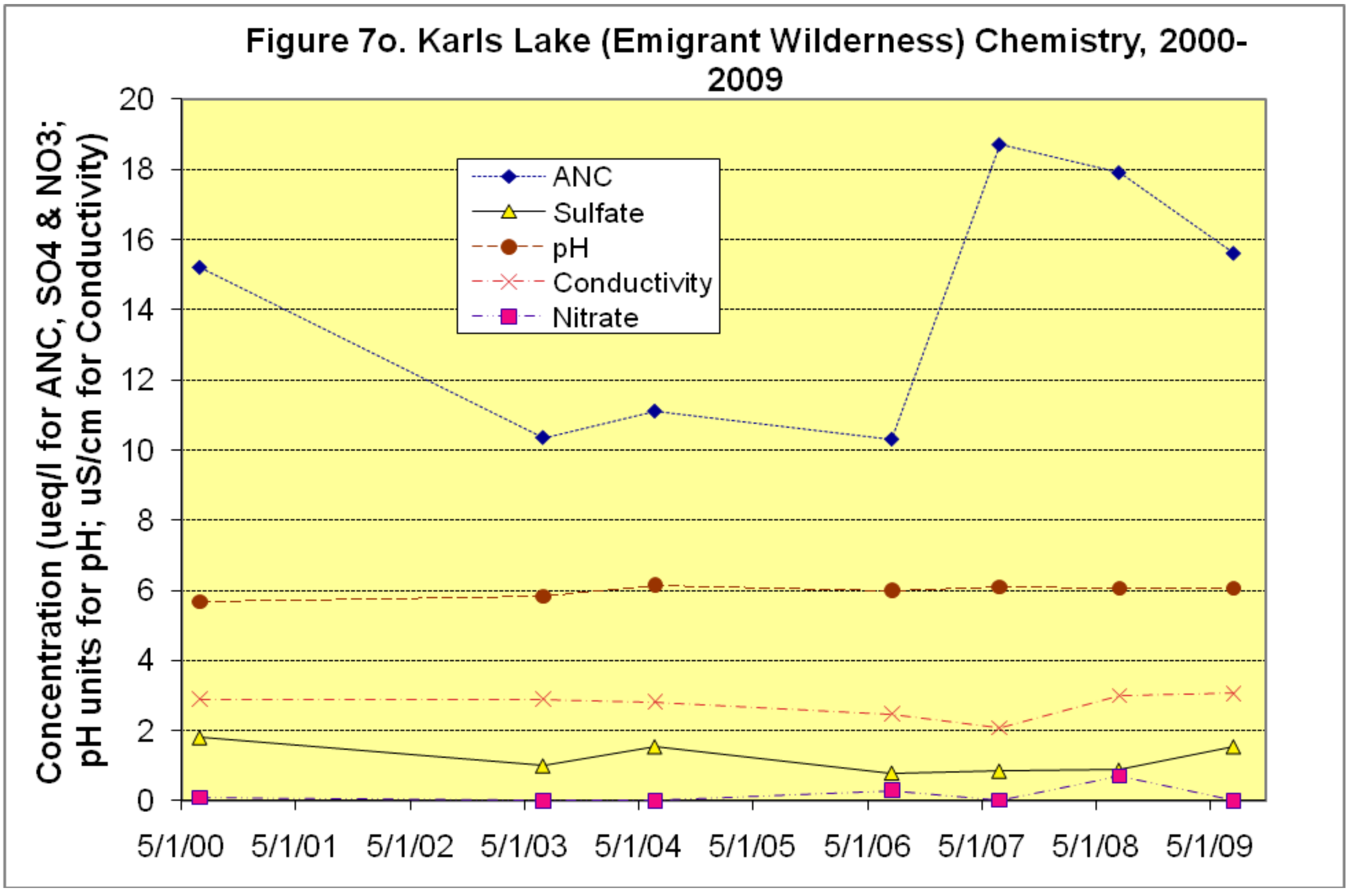


Figure 7o. Karls Lake (Emigrant Wilderness) Chemistry, 2000-2009
Concentration (ueq/l for ANC, SO4 & NO3; pH units for pH; uS/cm for Conductivity)
ANC
Sulfate
pH
Conductivity
Nitrate
20
18
16
14
12
10
8
6
4
2
0
5/1/00
5/1/01
5/1/02
5/1/03
5/1/04
5/1/05
5/1/06
5/1/07
5/1/08
5/1/09

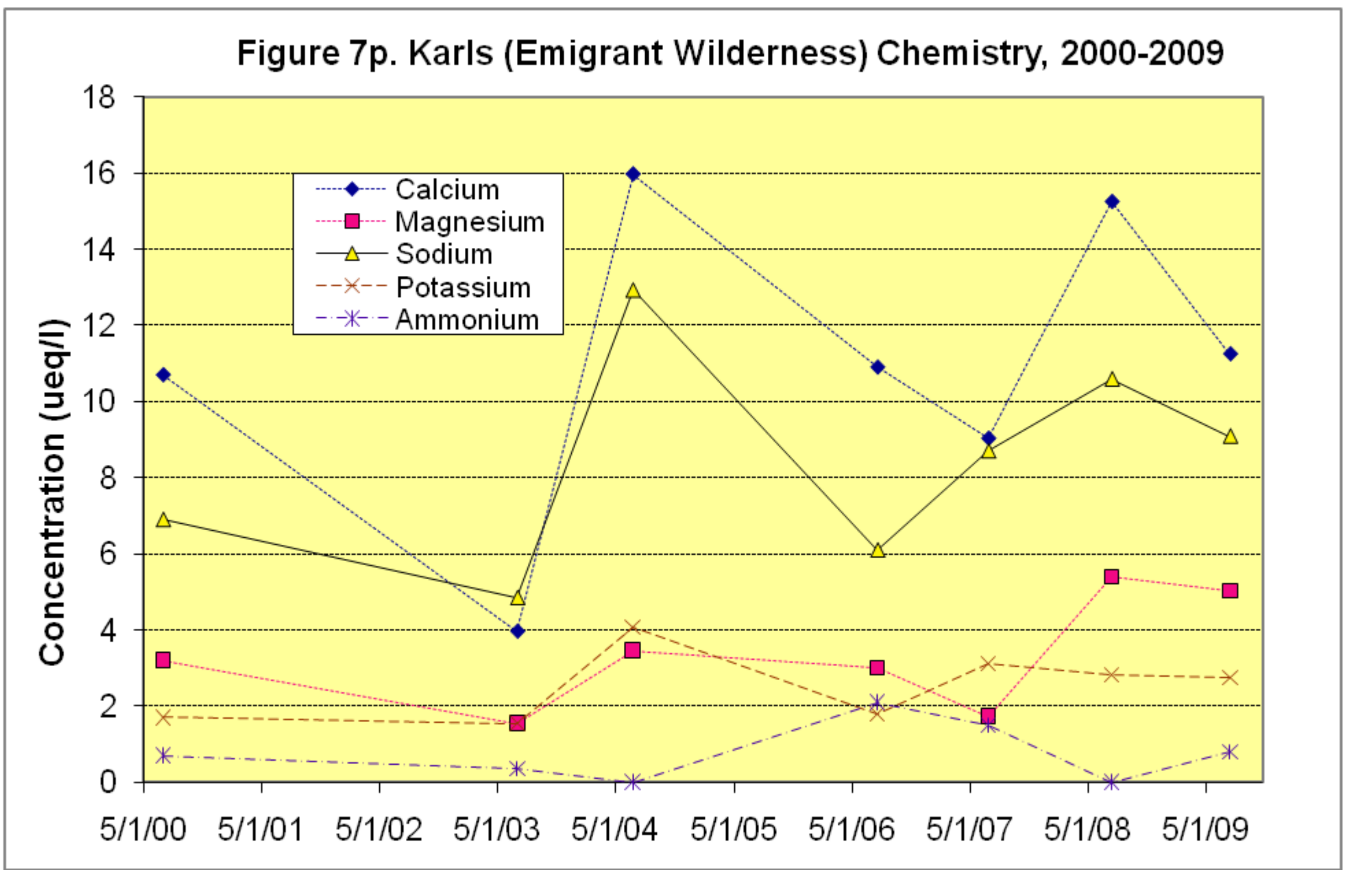


Figure 7p. Karls (Emigrant Wilderness) Chemistry, 2000-2009
Concentration (ueq/l)
Calcium
Magnesium
Sodium
Potassium
Ammonium
18
16
14
12
10
8
6
4
2
0
5/1/00
5/1/01
5/1/02
5/1/03
5/1/04
5/1/05
5/1/06
5/1/07
5/1/08
5/1/09

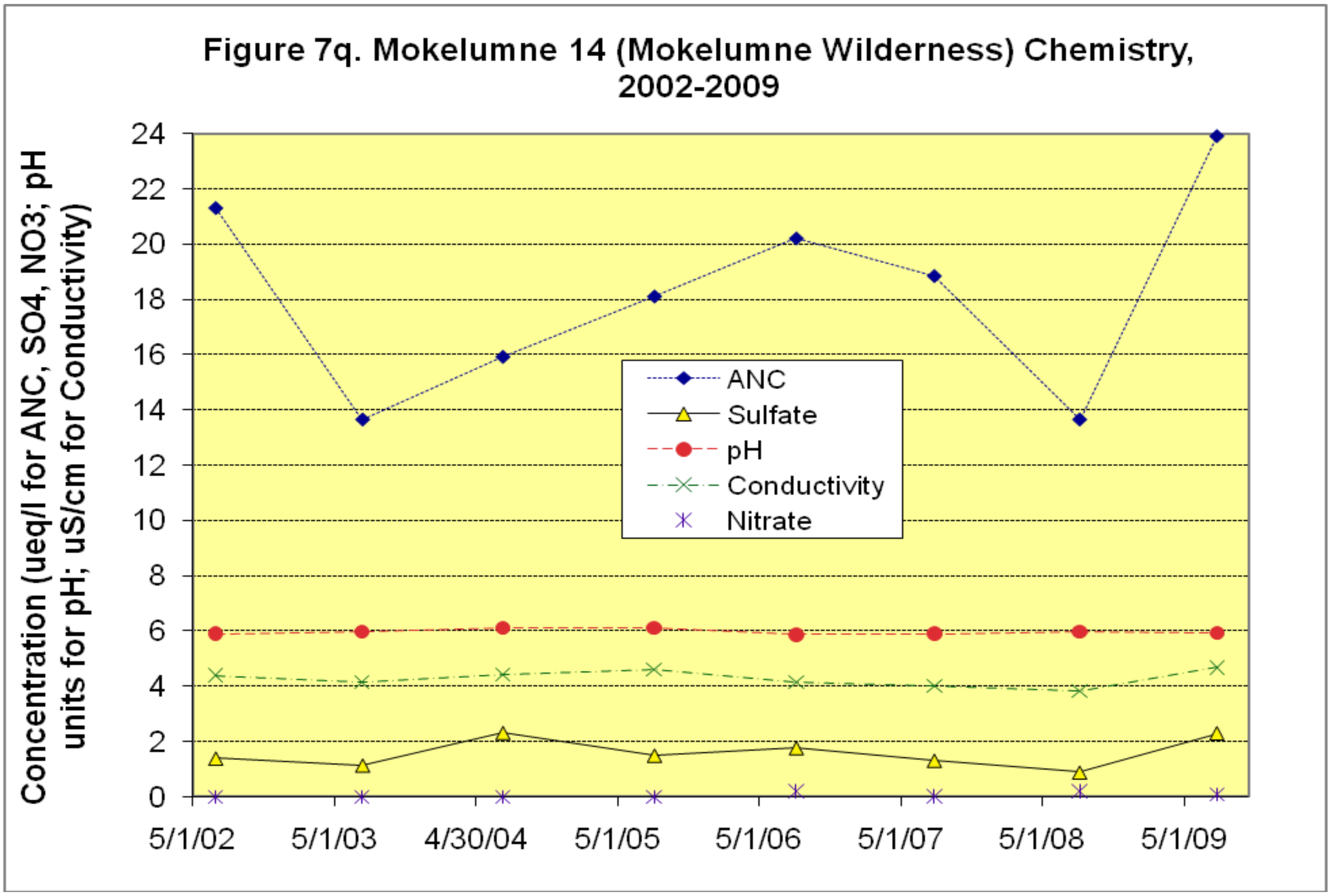


Figure 7q. Mokelumne 14 (Mokelumne Wilderness) Chemistry, 2002-2009
Concentration (ueq/l for ANC, SO4, NO3; pH units for pH; uS/cm for Conductivity)
0
2
4
6
8
10
12
14
16
18
20
22
24
5/1/02
5/1/03
4/30/04
5/1/05
5/1/06
5/1/07
5/1/08
5/1/09
ANC
Sulfate
pH
Conductivity
Nitrate

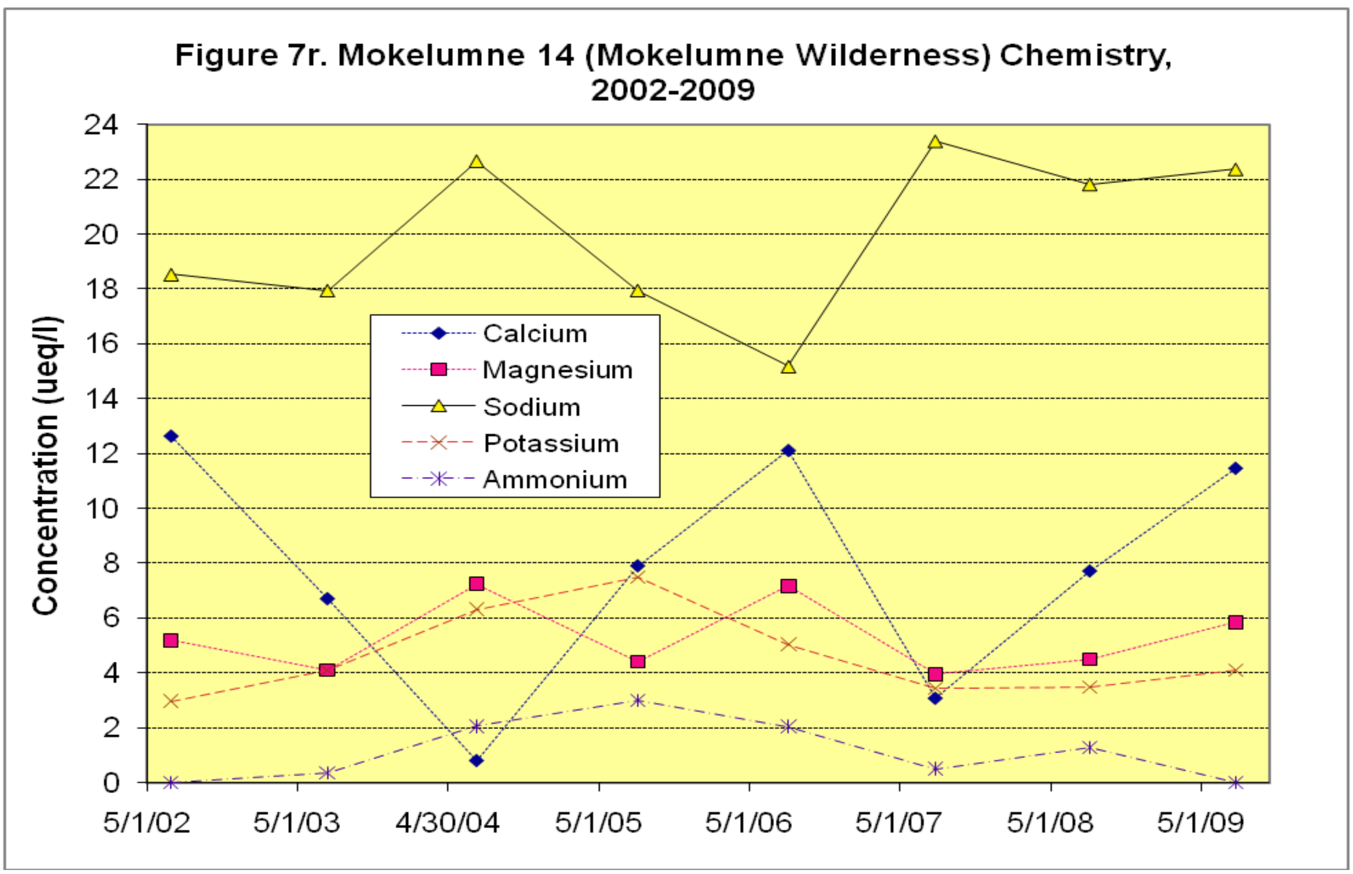


Figure 7r. Mokelumne 14 (Mokelumne Wilderness) Chemistry, 2002-2009
Concentration (ueq/l)
0
2
4
6
8
10
12
14
16
18
20
22
24
5/1/02
5/1/03
4/30/04
5/1/05
5/1/06
5/1/07
5/1/08
5/1/09
Calcium
Magnesium
Sodium
Potassium
Ammonium

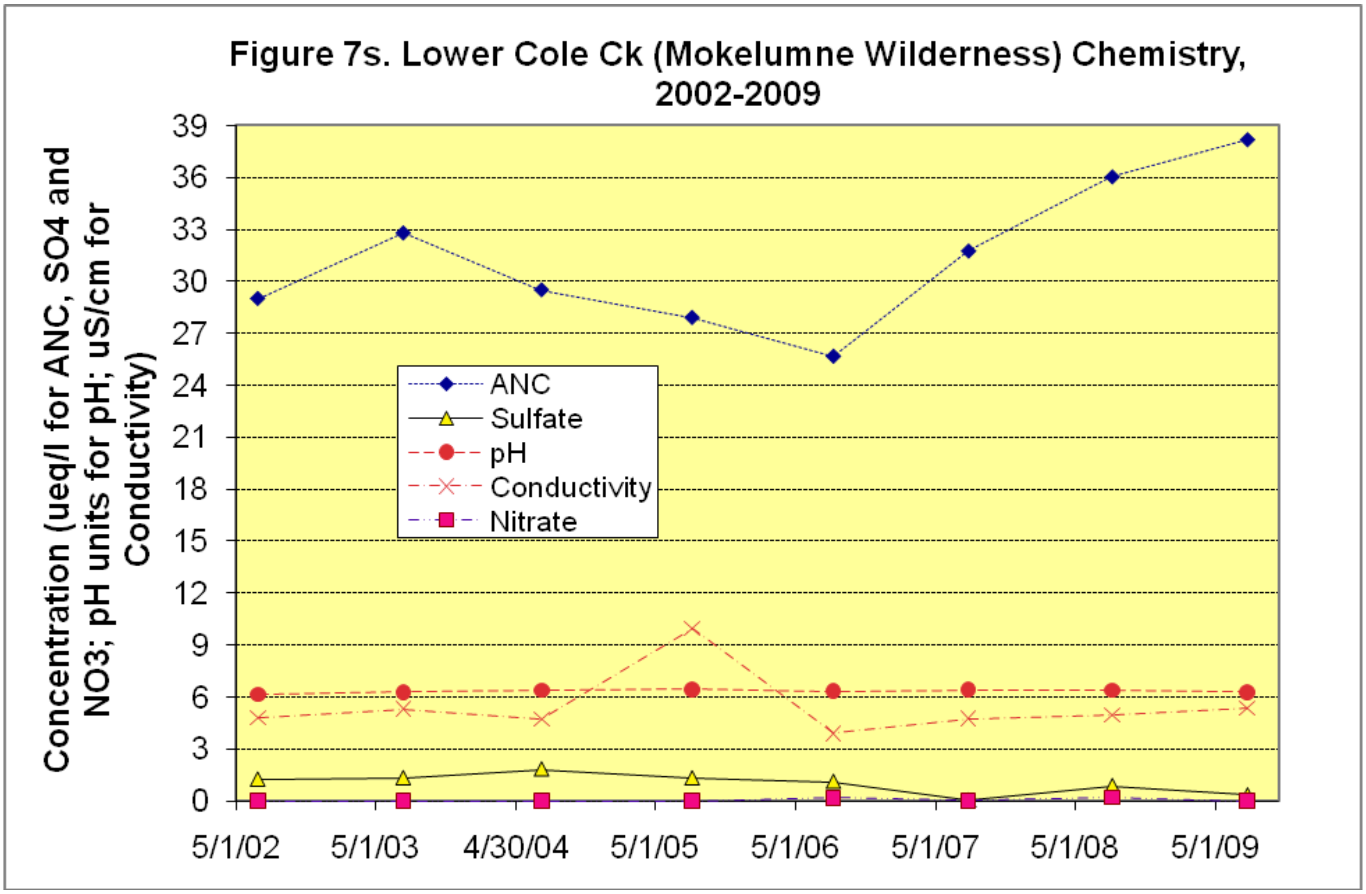


Figure 7s. Lower Cole Ck (Mokelumne Wilderness) Chemistry, 2002-2009
Concentration (ueq/l for ANC, SO4 and NO3; pH units for pH; uS/cm for Conductivity)
39
36
33
30
27
24
21
18
15
12
9
6
3
0
ANC
Sulfate
pH
Conductivity
Nitrate
5/1/02
5/1/03
4/30/04
5/1/05
5/1/06
5/1/07
5/1/08
5/1/09

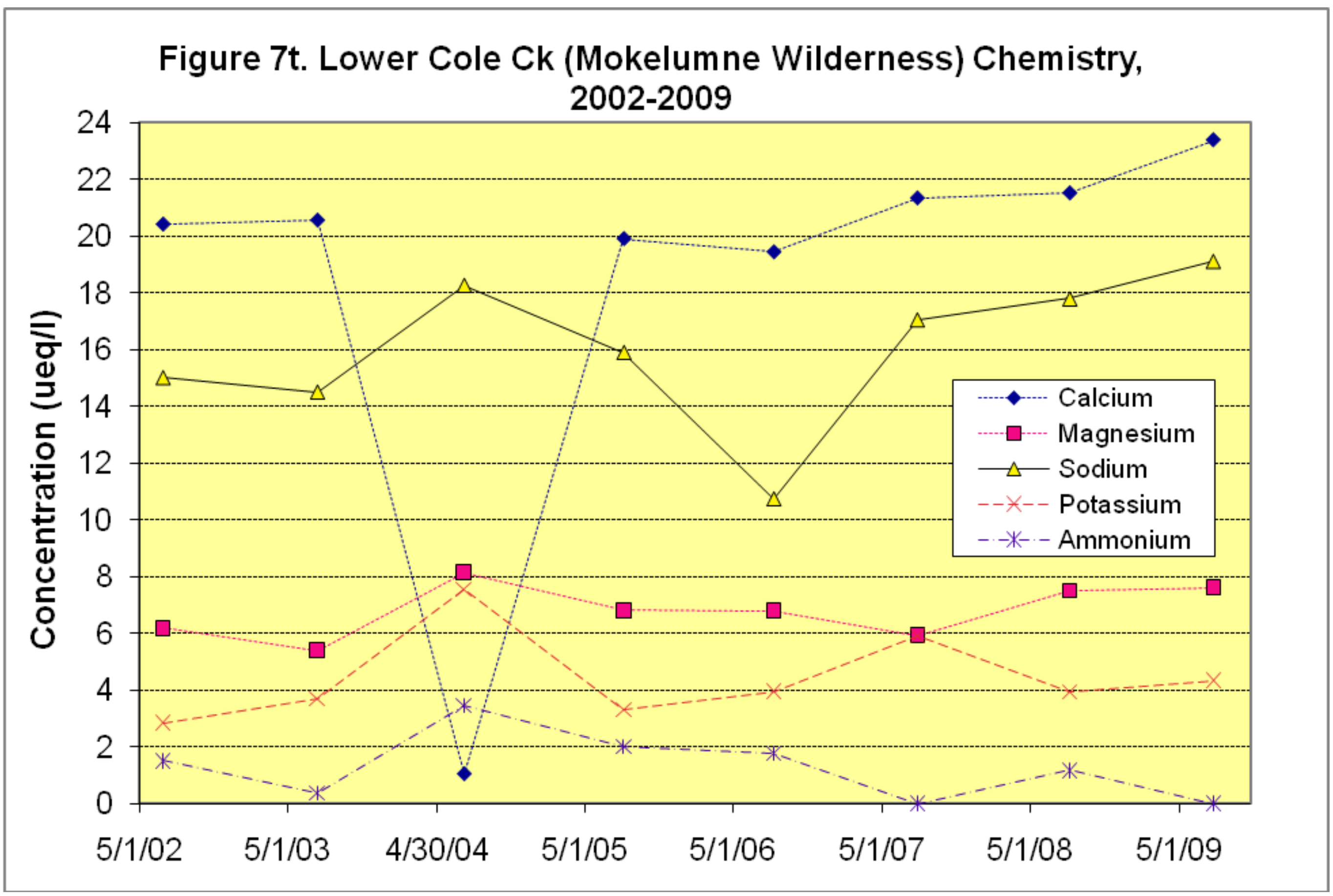


Figure 7t. Lower Cole Ck (Mokelumne Wilderness) Chemistry, 2002-2009
Concentration (ueq/l)
24
22
20
18
16
14
12
10
8
6
4
2
0
Calcium
Magnesium
Sodium
Potassium
Ammonium
5/1/02
5/1/03
4/30/04
5/1/05
5/1/06
5/1/07
5/1/08
5/1/09

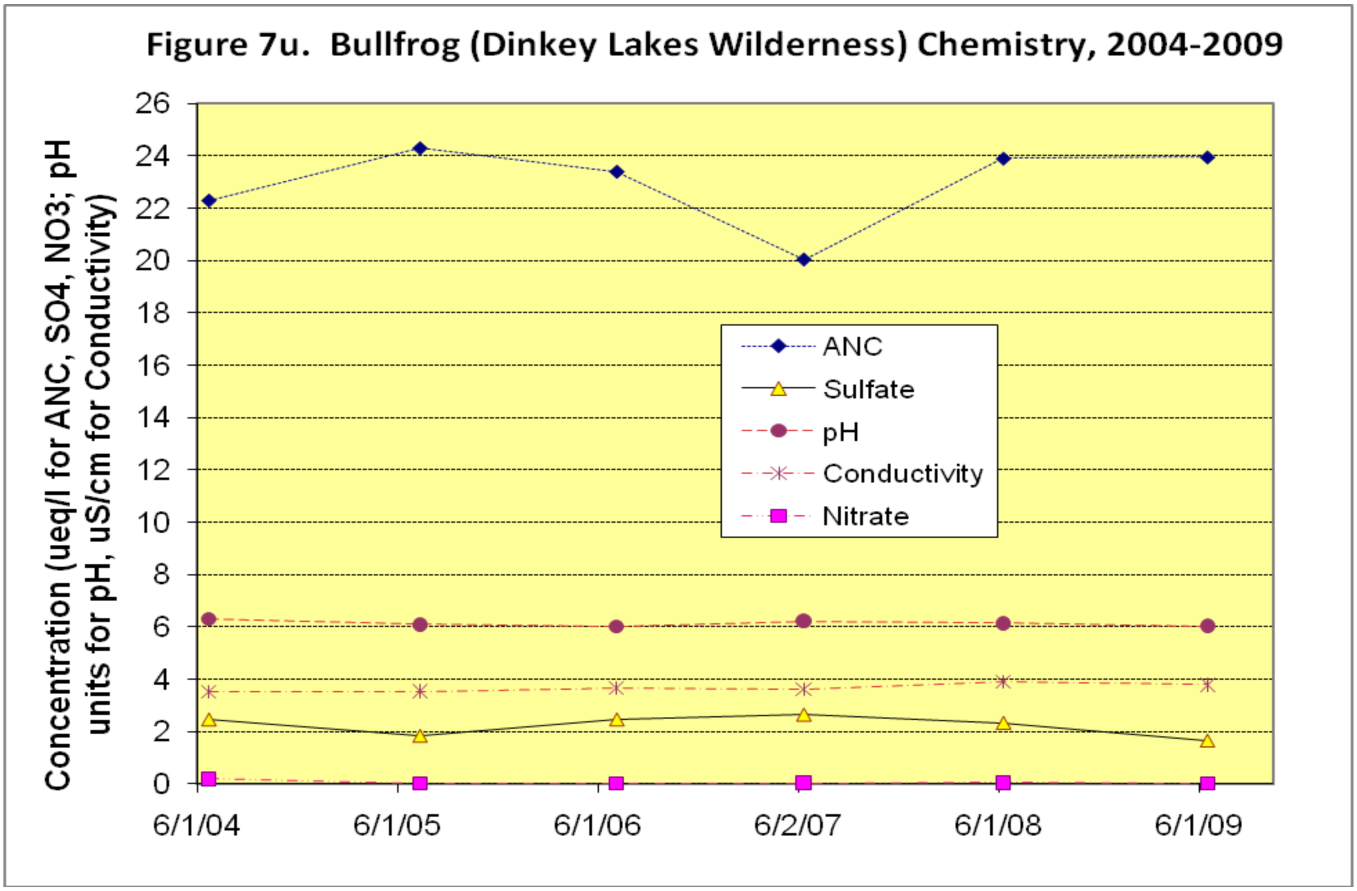


Figure 7u. Bullfrog (Dinkey Lakes Wilderness) Chemistry, 2004-2009
Concentration (ueq/l for ANC, SO4, NO3; pH units for pH, uS/cm for Conductivity)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
6/1/04
6/1/05
6/1/06
6/2/07
6/1/08
6/1/09
ANC
Sulfate
pH
Conductivity
Nitrate

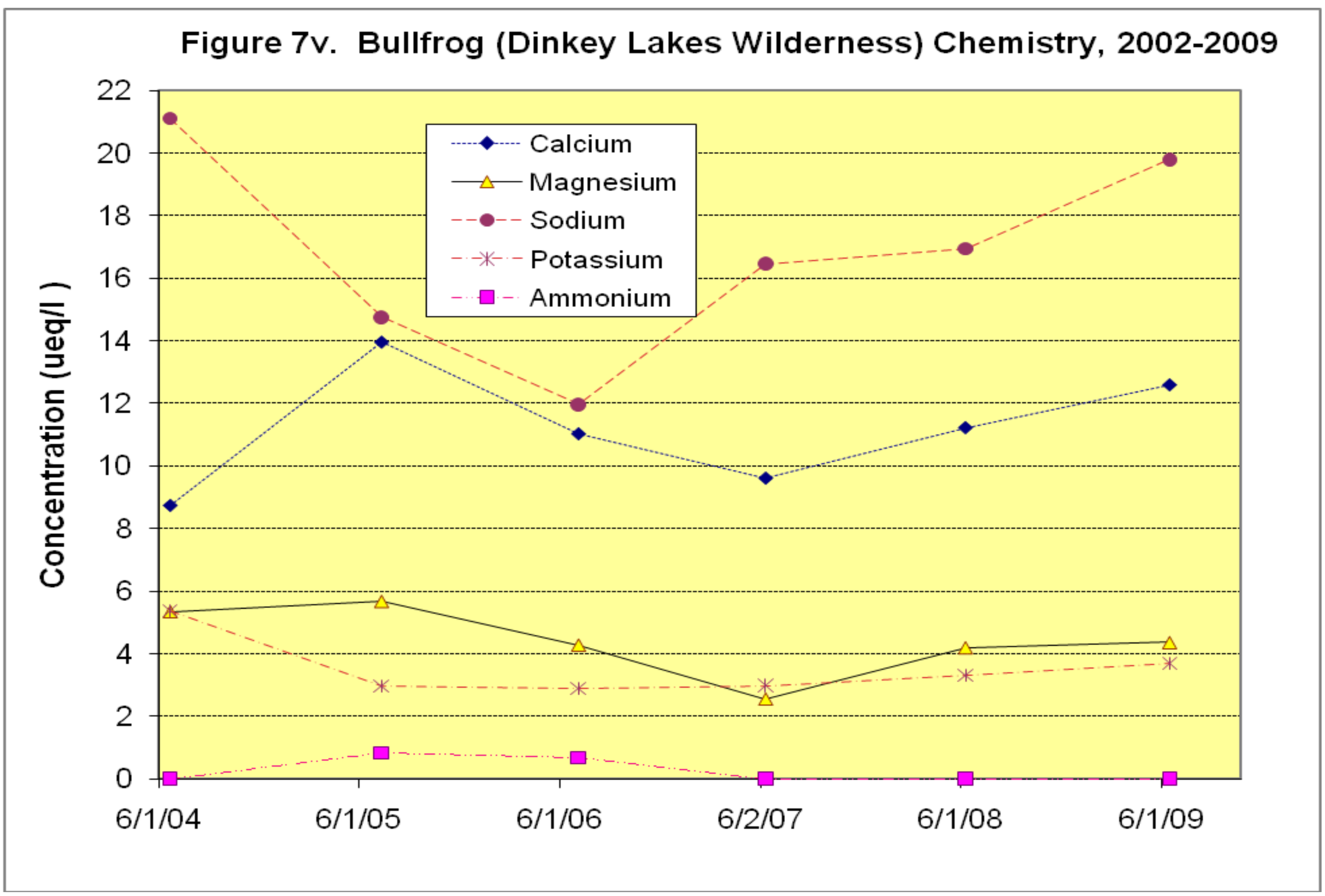


Figure 7v. Bullfrog (Dinkey Lakes Wilderness) Chemistry, 2002-2009
Concentration (ueq/l)
0
2
4
6
8
10
12
14
16
18
20
22
6/1/04
6/1/05
6/1/06
6/2/07
6/1/08
6/1/09
Calcium
Magnesium
Sodium
Potassium
Ammonium

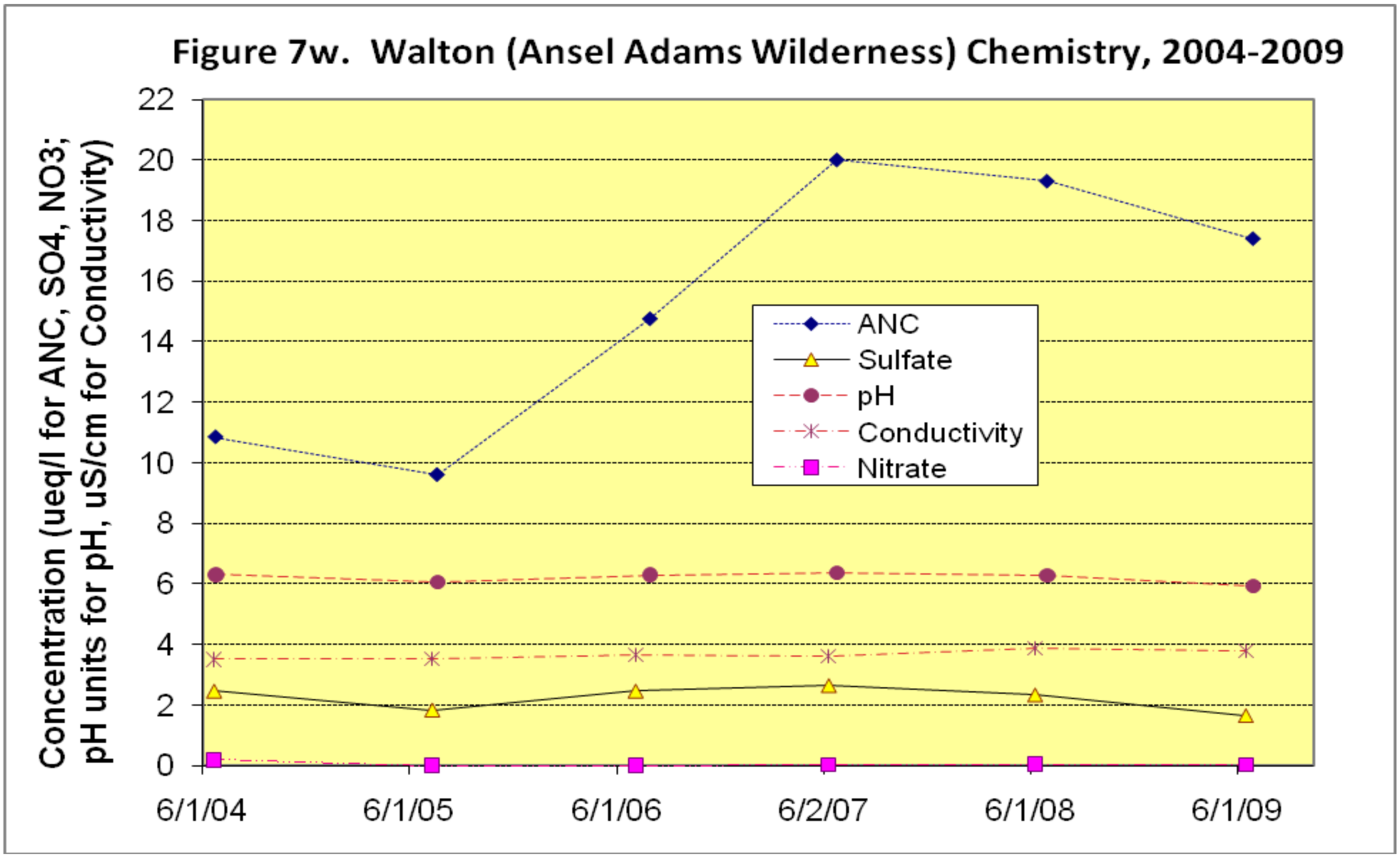


Figure 7w. Walton (Ansel Adams Wilderness) Chemistry, 2004-2009
Concentration (ueq/l for ANC, SO4, NO3; pH units for pH, uS/cm for Conductivity)
0
2
4
6
8
10
12
14
16
18
20
22
6/1/04
6/1/05
6/1/06
6/2/07
6/1/08
6/1/09
ANC
Sulfate
pH
Conductivity
Nitrate

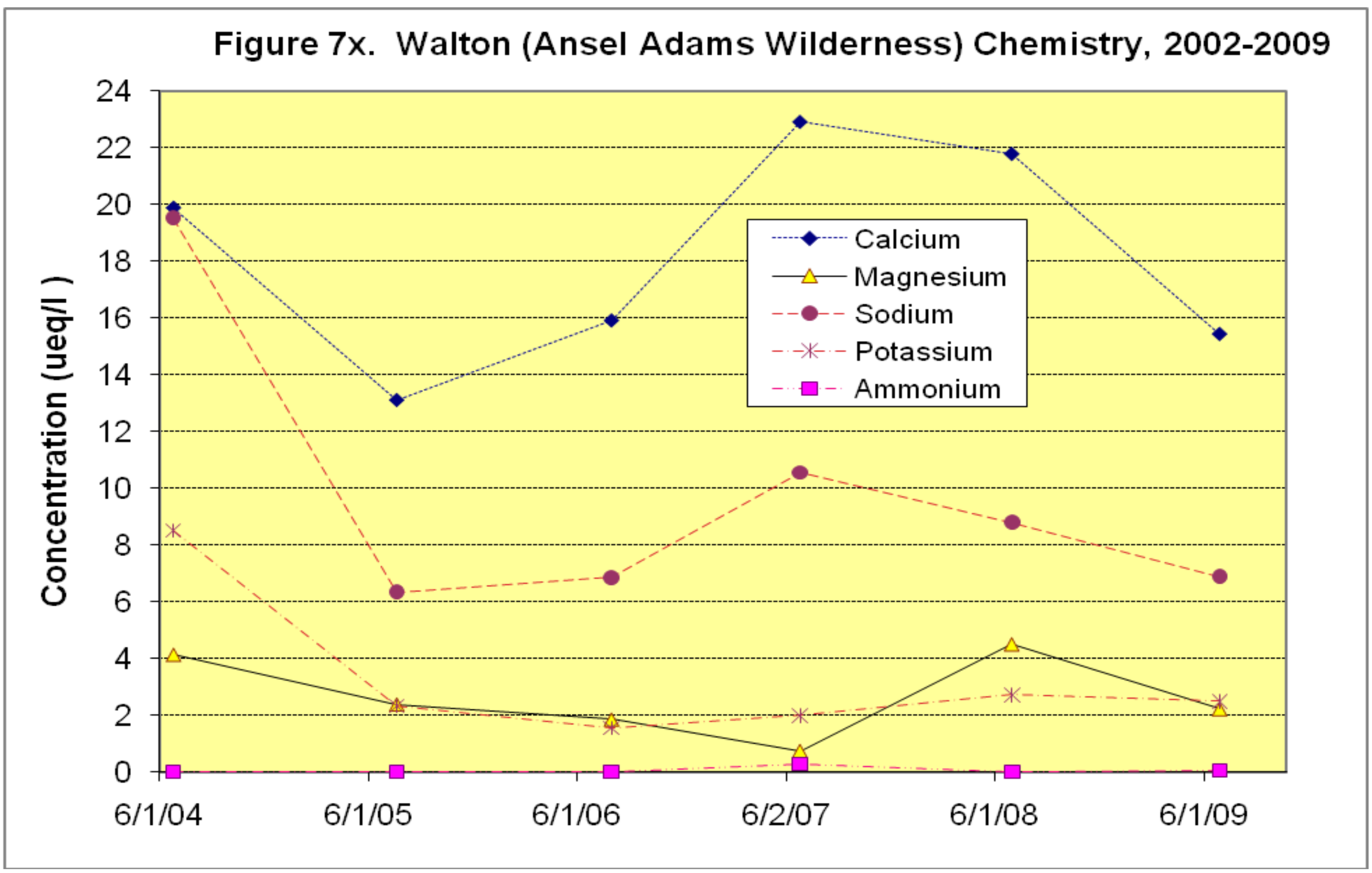


Figure 7x. Walton (Ansel Adams Wilderness) Chemistry, 2002-2009
Concentration (ueq/l)
0
2
4
6
8
10
12
14
16
18
20
22
24
6/1/04
6/1/05
6/1/06
6/2/07
6/1/08
6/1/09
Calcium
Magnesium
Sodium
Potassium
Ammonium

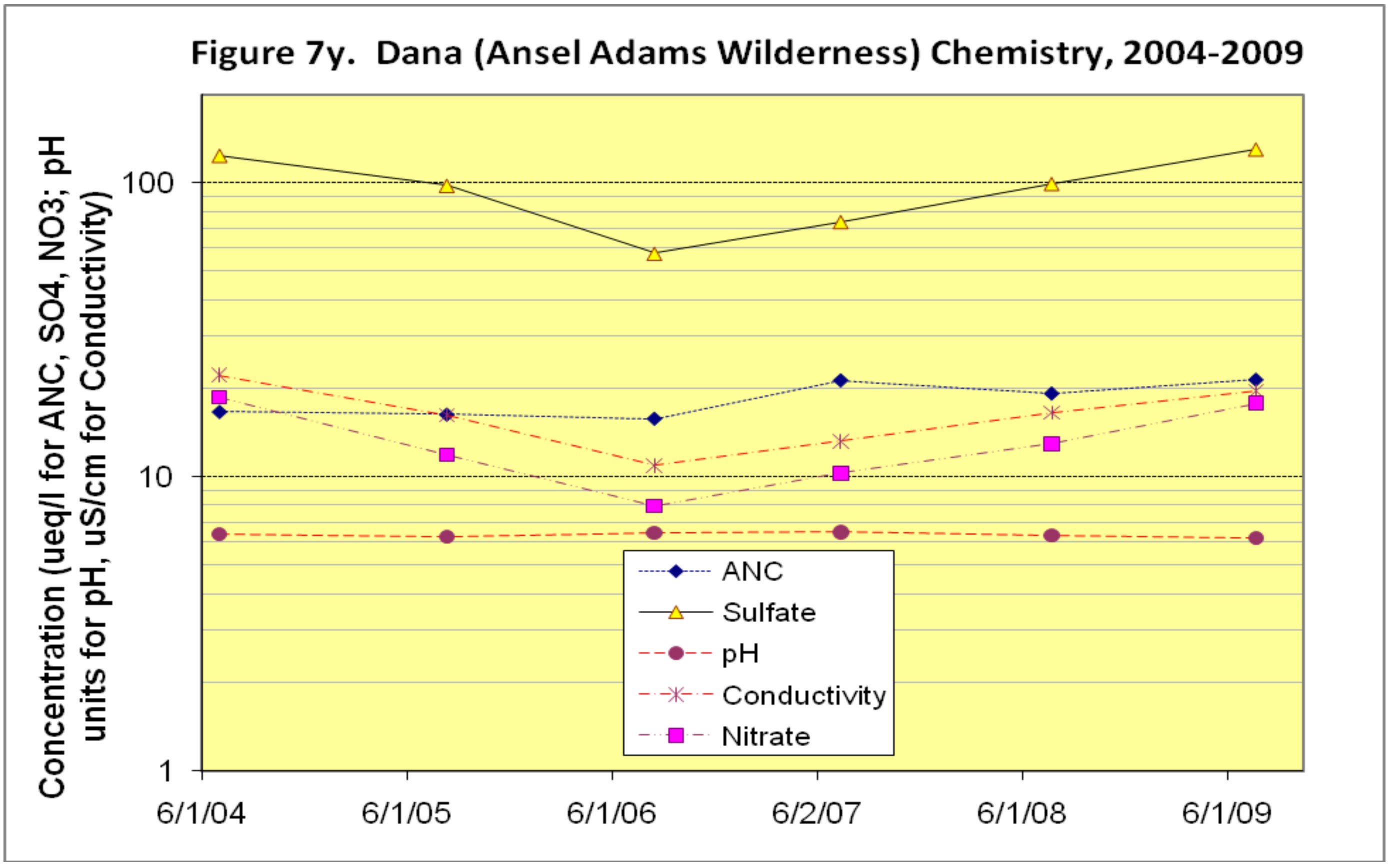


Figure 7y. Dana (Ansel Adams Wilderness) Chemistry, 2004-2009
Concentration (ueq/l for ANC, SO4, NO3; pH units for pH, uS/cm for Conductivity)
100
10
1
6/1/04
6/1/05
6/1/06
6/2/07
6/1/08
6/1/09
ANC
Sulfate
pH
Conductivity
Nitrate

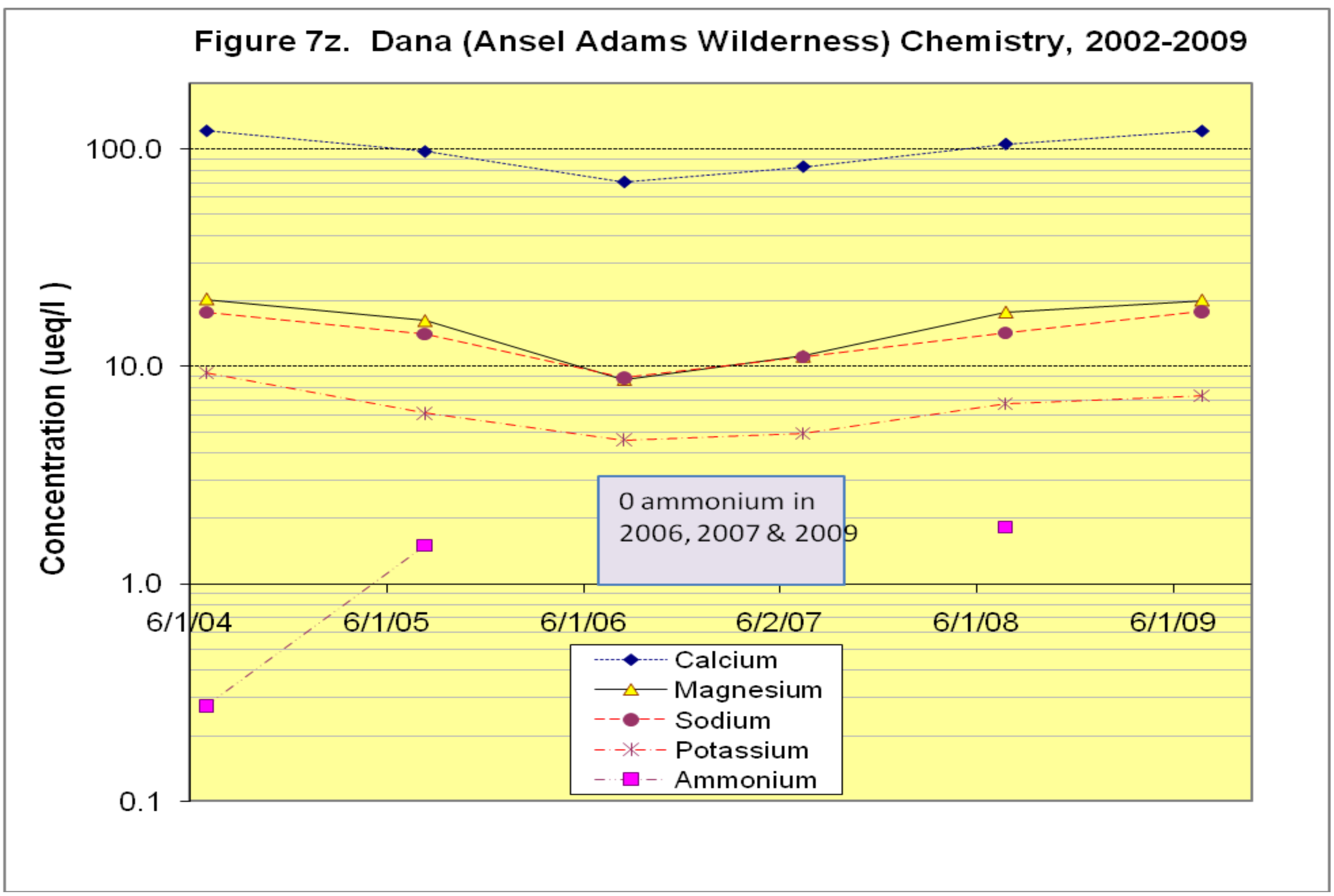


Figure 7z. Dana (Ansel Adams Wilderness) Chemistry, 2002-2009
Concentration (ueq/l)
100.0
10.0
1.0
0.1
6/1/04
6/1/05
6/1/06
6/2/07
6/1/08
6/1/09
0 ammonium in 2006, 2007 & 2009
Calcium
Magnesium
Sodium
Potassium
Ammonium

Except for ANC, the magnitudes of concentration changes between years are typically small, usually less than one μEq L^{-1} annually. During development of the monitoring component of the Sierra Nevada Framework extensive research identified that annual ANC, sulfate and nitrate changes less than 30% would not be cause for alarm (personal communications, Al Leydecker and Jim Sickman 2000). The sulfate percent changes in Figure 7 are typically less than 30%, even for the low concentrations levels at which very low absolute differences would generate relatively large percentage differences. With one exception ANC drops from 2008 to 2009 were also small. At Key Lake, however, ANC dropped from 18 μEq L^{-1} in 2008 to about 6 μEq L^{-1} in 2009. This drop is not interpreted to be practically significant because the 2008 ANC concentration was by far the highest on record and the 2009 6 μEq L^{-1} is well within the range of the 2000-2007 ANCs. ANCs increased at over 80% of the lakes from 2007 to 2008, with over 60% of all lakes having the highest ANC on record in 2008. Six lakes had their highest ANC on record in 2009, with Mokelumne 14's ANC almost doubling. Increasing ANC is potentially a good sign—acid buffering capacity is increasing.

At most lakes in the monitoring network nitrate concentrations are very low, and often undetectable. Although the 30% change criteria may be acceded at times during the full length of the monitoring project, the absolute change in nitrate concentration is usually less than 1 μEq L^{-1}, a low magnitude in terms of potential ecological effects. An exception is Dana Lake, where nitrate has always been in the 10-20 μEq L^{-1} range. Nitrate concentrations at Dana have increased gradually every year since 2006, and the relatively high 2009 nitrate concentration is not considered to be an issue. Elsewhere nitrate changes from 2008 to 2009 were generally down, a good sign.

Between 2008 and 2009 ANC and sulfate increased at about as many lakes as they decreased. Most lakes experienced calcium decreases from 2008 to 2009. These changes were generally within the "noise" envelope of the year-to-year concentration changes. For instance, the 2009 reductions in calcium follow 2008 when six lakes experienced the largest calcium concentrations on record and ten of eleven lakes had calcium increases.

The following table summarizes the results of the temporal trend analyses (from the beginning of each record—see table on page 4—through 2009). Normality testing, for each constituent at each location, showed that about 20% of the constituents were not normally distributed. To standardize the trend analyses and to be conservative, non-parametric trend testing was undertaken for all constituents. Hyphenated cells signify a non-significant trend (at $\alpha = 0.10$). Numerical values are the Sen slope estimate (Sen 1968) of significant temporal trends based on the Mann-Kendall test (Gilbert 1987). A negative value signifies a significant downward trend so that, for instance, over the 24-year sampling period at Waca Lake sulfate decreased approximately 0.14 μEq L^{-1} per year.

Lake	**Constituent**									
	ANC	Ca	NO^3	SO^4	Cl	K	Mg	Na	NH^4	pH
Waca	--	--	--	-0.14	-0.06	--	--	--	0.02	--
Long	--	0.85	--	--	--	--	--	--	--	--
Powell	0.84	--	--	--	--	--	--	--	--	--
Key	--	--	--	--	--	--	--	--	--	0.02
Smith	--	--	--	-0.12	--	0.04	--	0.11	--	--
Mokelumne14	--	--	--	--	--	--	--	--	--	--
Lower Cole Ck	--	--	0.04	-0.15	--	--	--	--	--	--
Hufford	--	--	0.05	-0.20	--	--	--	--	--	--
Caribou8	--	--	--	--	--	--	--	--	--	--
Karls	--	--	--	--	--	--	--	--	--	--
Dana	--	--	--	--	--	--	--	--	--	--
Walton	--	--	--	--	--	--	--	--	--	--
Bullfrog	--	--	--	--	--	--	--	--	--	--

The primary long-term trends of practical significance are increases in ANC at Powell Lk, calcium at Long Lk, and sulfate decreases at four lakes, Waca, Smith, Lower Cole Ck, and Hufford. In terms of acidification and nitrification, these changes are not detrimental, and in fact suggest the potential for reduced inputs of acidic compounds. In 2009 long-term sulfate decreases were statistically identified at two additional lakes, Hufford and Lower Cole Ck, where decreases had not been evident in prior years.

Some of the other statistically significant changes may be spurious. For instance, constituents like nitrate, typically with very low or non-detectable concentrations, first showed statistically significant trends (e.g., Lower Cole Ck Lk) when laboratory instrumentation was changed and detection limits changed. Also the statistical testing follows a typical convention of assigning one-half of the detection limit value for non-detects. When the detection limit changed a spurious significance could result based largely on the detection limit change.

5.2.1 Waca

Waca Lake is located immediately west of the crest of the Sierra Nevada at approximately 2,495 m elevation about 12 km southwest of Lake Tahoe. It is one of many adjacent lakes in the Desolation Valley section of Desolation Wilderness. Waca is a headwater lake in granodiorite terrain with little vegetation on its watershed. The lake occupies about 2 hectares within a 10-hectare, south-west facing watershed. During surveys between 2002 and 2004, and 2006 to 2008, the maximum water depth at Waca was about 11 m, and a Secchi disk was usually visible at the lake bottom. In autumn 1991 fish were observed in Waca.

Waca Lake has the longest monitoring record in the Region 5 network, now fourteen sample collections, starting with the Western Lake Survey in 1985 (Figures 7a and 7b). A down trend in sulfate, first identified at Waca in 2004, parallels the general trend downward in the atmospheric wet deposition and sulfate concentration recorded at long-term deposition monitoring locations in Yosemite and Sequoia-Kings Canyon National Parks (NADP 2006). At Waca sulfate concentrations in the 4-6+ μEq L^{-1} range between 1985 and 1993 have more recently dropped to the 2-3+ range, with the lowest recorded value, 1.7 μEq L^{-1} in 2006. The annual rate of sulfate decline since 1985 is 0.14 μEq L^{-1}.

In 2009 minor statistical changes in chloride (0.06 μEq L^{-1}) and ammonium (0.02 μEq L^{-1} increase) occurred. These small rates of change do not suggest that any management action need to be taken. As with many of the other lakes, concentrations at Waca of most cations decreased from 2008 but typically back toward the long-term median (Figure 7b). Statistically significant changes in sodium in 2007, and calcium and chloride in 2008 were not repeated in 2009.

The 30% change criterion, mentioned above as an indicator of potential concern, is not met in 2009 for ANC, nitrate or sulfate but is met for calcium. The 2009 calcium concentration returns to the typical historical range after a spike upwards in 2008. The drop in calcium is not believed to foretell acidification because ANC in 2009 is the highest on record for Waca Lake.

5.2.2 Key

Key Lake, located in the north-central portion of Emigrant Wilderness at 2,799 m elevation and almost due east of San Francisco, drains a west-facing catchment approximately 6 hectares in area. This headwater lake is small, at 1 hectare area. The bedrock geology is similar to much of the Sierra Nevada dominated by felsic materials such as granodiorite, diorite, tonalite and felsic gneiss and schist. There is very little vegetation in the Key Lake watershed. Key Lake is relatively shallow, less than 3 m maximum depth, and during surveys between 2002 and 2007 a Secchi disk was always visible at the lake bottom.

The 2008-2009 ANC difference meets the 30% triggering value, but even with a drop of 12 μEq L^{-1} the 2009 ANC concentration is back in to the mid-range of the pre-2008 concentrations, and consequently the decrease is not seen as a cause of alarm. As with several other lakes, cation concentrations all dropped (typically 2-3 μEq L^{-1}) from 2008 to 2009.

None of the constituent concentrations plotted in Figure 7c or 7d show an obvious trend through the full monitoring period; increases are typically followed by decreases (or vice versa), and only the pH trend is statistically significant in 2009. Because pH is scaled logarithmically, a 10-fold change in hydrogen ion concentration is represented by a one unit change in pH. Consequently plotting of pH on a linear scale masks changes. At Key Lake a statistically significant increase in pH was identified for the first time in 2007, and again in 2008. The long-term increase is relatively small, 0.02 pH unit, and not believed to be practically significant.

5.2.3 Long

Long Lake occupies a moderately large (63 ha), north-facing headwater catchment in the northeastern section of Kaiser Wilderness about 75 km northeast of Fresno. At 2,725 m elevation, Long Lake is in the same general elevation range as most of the other lakes assessed for temporal trends. It has more vegetation than many other Sierran wilderness lakes, with about one-half of the granodiorite-dominated catchment in vegetation identifiable from aerial photos. The lake occupies about 3.8 ha area and is backed by a 400-m headwall immediately due south. During surveys between 2002 and 2004, and 2006 to 2008, a Secchi disk was visible about one-half the way to the maximum depth of the lake (14 m).

ANC at Long Lake is higher than at most of the other lakes monitored in the western Sierra, but decreased in 2009 about 10% after a substantial increase from 2007 to 2008 (Figure 7e). Concentrations of most cations dropped one to a few microequivalents per liter from 2008 to 2009. A statistically significant calcium increase in 2008 persisted into 2009, with the long-term trend equating to 0.85 $\mu Eq\ L^{-1}$. At Long both calcium and sodium concentrations are also slightly higher than at the other Sierran lakes. No concentration change for any constituent met the 30% annual change criterion.

5.2.4 Powell

Powell Lake drains a north-facing, 32-ha catchment in the western portion of Emigrant Wilderness. This headwater lake is slightly lower down on the western slope of the Sierra than most other lakes in the LAKES network. Powell's area is about 1.6 ha and its elevation is 2,685 m. As with many of the other lakes detailed here, Powell's catchment is dominated by granodiorite. Almost one-half of the catchment is well-vegetated. Between 2002 and 2008 Secchi disk transparency was usually over 6 m and maximum lake depth was about 8 m.

The only statistically significant temporal trend from the epilimnion sampling at Powell is a 0.85 $\mu Eq\ L^{-1}$ annual increase in ANC. Similar to Long Lake, at Powell there has been very little variation through time in conductivity, magnesium, potassium, ammonium, sulfate, and pH (Figures 7g and h). And similar to most monitored lakes nitrate concentrations have been very low, and at Powell were below the detection limit for all five surveys between 2000 and 2005, 2007 and 2009. None of the annual ANC, sulfate or nitrate concentration changes at Powell Lake meet the 30% criterion.

5.2.5 Smith

Smith Lake, located about 4 km west of Waca Lake at the western edge of Desolation Wilderness, lies in a west-facing catchment with a 300-m headwall immediately east of the lake. This 2,649 m elevation lake occupies about 10% of its 35-ha granite-dominated catchment. Mapping software identifies Smith Lake as dammed. A concern is that chemicals could leach from a dam and confound assessment of atmospheric effects on the lake's chemistry. Field work identifies the dam as a small wooden one that presumably is not influencing lake water chemistry in terms of atmospherically-derived chemical constituents. At 34 m, Smith is the deepest Sierran lake in the LAKES monitoring network. Its transparency between 2006 and 2008 ranged from 9.75 to over 15 m (the Secchi disk measurement in 2007 was limited by a 15-m line length).

Waca and Smith Lakes have had statistically significant sulfate decreases for several years. As with Waca, the trend is relatively small at Smith, down 0.12 $\mu Eq\ L^{-1}\ yr^{-1}$. Sulfate concentrations dropped from the 6-8 $\mu Eq\ L^{-1}$ range in the mid-1980s to the 4-5 $\mu Eq\ L^{-1}$ range more recently, with the lowest concentration, 3 $\mu Eq\ L^{-1}$, recorded in 2009. A minor statistical increase in potassium identified at Powell in 2007 and 2008 was not evident in 2009. To varying degrees, other constituents share visually decreasing and increasing ionic concentration patterns through time (Figures 7i and j). The patterns may be due partly to potentially differing sampling protocols and (or) laboratories analyzing the samples. For instance at Smith Lake in 1985 and 1986 the samples were analyzed by K. McCleneghan, a contract researcher for the California Air Resources Board (McCleneghan et al. 1987), in the early 1990s by the University of California, Santa Barbara, and since then by RM.

A 6 $\mu Eq\ L^{-1}$ ANC drop in 2007 was not sustained in 2008 or in 2009 (Figure 7i) and ANC in 2009 approximates the levels in 2005 and 2006. Although both calcium and magnesium concentrations decreased from 2008 to 2009 by more than 30%, the absolute magnitude of the decreases is small, and the 2009 concentrations of both constituents are well within the historical range.

5.2.6 Caribou 8

At 2,131 m elevation, Caribou8 Lake lies in the southern third of Caribou Wilderness, about 14 km north of Lake Almanor and 48 km west northwest of Susanville. The lake is about 1 ha in area within an east-facing catchment of 32 ha area. In surveys from 2003 to 2007 Caribou8 was always transparent to the bottom of its 3 m maximum depth. Along with the rest of the Cascade Range, Caribou Wilderness is dominated by volcanic rock. About three-quarters of the terrain in the Wilderness at the elevation of Caribou8 is a blanket of lodgepole pine and red fir.

ANC at Caribou8 has typically been in the mid-20 $\mu Eq\ L^{-1}$ range (Figure 7k), although relatively minor increases from 2007 through 2009 push the 2009 ANC concentration to the highest on record, over 31 $\mu Eq\ L^{-1}$. No recent single year change of any acidifying constitutent or nutriet has met the 30% threshold. Compared to other lakes in the R5 monitoring network, Caribou8 has relatively high concentrations of magnesium—atypically higher than calcium concentrations—and relatively low sodium concentrations. These differences may be due to the preponderance of volcanic terrain in the Wilderness. A significant temporal downtrend for sodium identified in 2007 was not sustained in 2008 or 2009, when sodium concentration was the highest on record (Figure 7l). No other statistically significant temporal trends were identified in 2009 and 2009 changes in nitrate or sulfate did not reach the 30% criterion.

5.2.7 Hufford

Hufford Lake occupies a 29-ha, north-facing catchment near the center of Thousand Lakes Wilderness in the southern Cascades. The lake itself occupies about 2.6 ha at 2,056 m elevation, below a 2,180 m ridge about 69 km west of Redding. Between 2003 and 2007 Secchi disk transparency was usually to 8+ m, the maximum lake depth. This lake also is not a headwater lake and sits 0.2 km below a smaller lake. Volcanic bedrock dominates this Wilderness and because of the small size of the Wilderness, and its relative accessibility, the fewer than ten perennial lakes in the Wilderness receive significant recreational use.

During the eight-year monitoring period ANC has ranged from 28 to 46 $\mu Eq\ L^{-1}$, somewhat higher than for lakes in the central and southern Sierra Nevada (Figure 7m). Similarly, sulfate, calcium, sodium and magnesium concentrations have been relatively high (Figures 7m and 7n). A minor (0.05 $\mu Eq\ L^{-1}$) statistically significant increase in nitrate first identified in 2008 was sustained in 2009. For the first time a statistically significant decrease in sulfate was identified in 2009. Changes in ANC, sulfate and nitrate concentrations did not reach the 30% criterion in 2009.

5.2.8 Karls

Karls Lake occupies a moderately large (74 ha), south-facing headwater catchment in the south-central section of Emigrant Wilderness about 240 km east-northeast of San Francisco. At 2,528 m elevation, Karls Lake is at a slightly lower elevation compared to most of the other Sierran lakes assessed for temporal trends. About one-quarter of the granodiorite-dominated catchment has vegetation identifiable from aerial photos. The lake occupies about 8.6 ha area and is backed by a 75-m headwall immediately north and northwest. During surveys in 2003, 2004, 2006 and 2007, Secchi disk transparency was usually down to the maximum depth of the lake (5 m).

The water chemistry of Karls Lake is typical of other dilute lakes in the higher elevations of the Sierra Nevada. ANC has been low, at 19 $\mu Eq\ L^{-1}$ or less during all sample collections. pH has hovered about 6.0, and nitrate and sulfate have been low or below detection at all sample collections. The 30% change criterion was not met in 2009 by ANC or nitrate. Sulfate concentration, however, increased from 0.9 to over 1.5 $\mu Eq\ L^{-1}$ from 2008 to 2009. This relatively small absolute change is not interpreted to have practical significance. No statistically significant temporal trends were identified for any constituent as of 2009.

5.2.9 Mokelumne 14

Mokelumne 14 is a headwater lake at 2,545 m elevation near the northwest border of Mokelumne Wilderness, about 66 km east-southeast of Placerville and 11 km southwest of Carson Pass. Mokelumne 14 is shallow, with a maximum depth of about 2.5 m, and was transparent to the bottom during surveys in 2003-2004 and 2006-2008. The south-facing catchment of this 1-ha lake occupies about 45 ha on granodioritic terrain. About two-thirds of the catchment is vegetated and between 2002 and 2004 Secchi disk transparency was to the bottom of the lake.

Mokelumne 14 has typically had ANC concentrations between 14 and 21 $\mu Eq\ L^{-1}$, undetectable nitrate, and sulfate concentrations below 2 $\mu Eq\ L^{-1}$ (Figure 7s). No temporal changes were identified for any chemical constituent at Mokelumne 14 between 2002 and 2009 and the chemistry of this lake approximates that of most other Sierran lakes in the monitoring network (Figure 7). An ANC increase of over 10 $\mu Eq\ L^{-1}$ from 2008 to 2009 is the largest ANC increase in 2009 of any monitored lake. Although reasons for the increase aren't obvious the increase implies added buffering capacity for Mokelumne 14. An almost 4 $\mu Eq\ L^{-1}$ increase (over 30%) in Ca in 2009 and minor increases in potassium and sodium concentrations in 2009 parallel the ANC increase.

5.2.10 <u>Lower Cole Creek</u>

Lower Cole Ck is a 6-m deep, 1-ha lake located at 2,435 m elevation near the northwest border of Mokelumne Wilderness, about 15 km southwest of Carson Pass. The lake lays in a northwest-facing, 46-ha catchment that maxes out in elevation only about 15 m above lake level. Lower Cole differs from most other lakes in the monitoring network in being the third in a chain of lakes. The two lakes above Lower Cole Ck Lk are equal in area or smaller than Lower Cole Ck. Catchment geology is similar to most of the other Sierra Nevada monitoring lakes, with a preponderance of felsic bedrock. About 80% of the lake catchment is vegetated. Between 2003 and 2007 Secchi disk transparency at Lower Cole Ck decreased from over 5 m (to bottom) to less than 4 m.

ANC is relatively high for Lower Cole Ck Lake, compared to other lakes in the LAKES network, and has increased annually since 2006, to an historical high in 2009 of over 38 $\mu Eq\ L^{-1}$. Sulfate and nitrate concentrations have been low at Lower Cole Ck, and suggest no imminent concern for either acidification or nutrients. A statistically significant increase initially identified in 2008 for nitrate continued into 2009, but the slope of the trend line is low (0.04 $\mu Eq\ L^{-1}\ yr^{-1}$) and is not interpreted to be an issue (Figures 7s and t). A statistically significant decrease in sulfate (0.15 $\mu Eq\ L^{-1}\ yr^{-1}$) was identified for the first time at Lower Cole Ck Lake in 2009.

5.2.11 <u>Bullfrog</u>

Located in Dinkey Lakes Wilderness, Bullfrog is a moderately high-elevation lake (2,875 m) in an east-facing basin that tops out at about 3,015 m elevation. Bullfrog is located 80 km northeast of Fresno. Each year between 2006 and 2008 Bullfrog was clear to its 9-m bottom.

Bullfrog's chemistry is generally typical of other lakes in the monitoring network. It's ANC has ranged from 20 to 24 $\mu Eq\ L^{-1}$. Sulfate, nitrate, and potassium concentrations have varied little during the 6-year monitoring period and have usually been below 4 $\mu Eq\ L^{-1}$. Calcium has varied from 9 to 14 $\mu Eq\ L^{-1}$ and sodium has varied from 12 to 21 $\mu Eq\ L^{-1}$. No statistically significant temporal trends have been identified at Bullfrog.

5.2.12 <u>Walton</u>

Walton Lake, located in Ansel Adams Wilderness, is about 105 km east-northeast of Merced. Walton's 52-hectare basin is dominated by felsic rock. The basin is almost entirely free of major vegetation, and faces south. This headwater lake sits at 3,560 m elevation, about 150 m lower than the basin ridge boundary to the north. Walton's water surface area is small, about 1 hectare. Secchi disk measurements in 2006 and 2007 both were clear to the bottom at the 3.8 m deep monitoring location. During the Western Lake Survey, maximum lake depth was 3.7 m.

Walton's water chemistry shares characteristics with other central Sierran lakes in the monitoring network. ANC is low (10-20 $\mu Eq\ L^{-1}$), and calcium and sodium are 10-20 $\mu Eq\ L^{-1}$. Sulfate and nitrate concentrations are both low, 2-3 $\mu Eq\ L^{-1}$ and typically undetectable respectively. No statistically significant concentration changes have been identified for the 6-year monitoring span. ANC increases in 2006 and 2007 have not been sustained (Figure 7w).

5.2.13 <u>Dana</u>

Just east of the crest of the Sierra near Yosemite National Park, Dana Lake, in Ansel Adams Wilderness, lies at 3,400 m elevation at the base of a northwest-facing cirque. Dana is 100 km due east of Sonora and 14 km west-southwest of Mono

Lake. The lake is in a 124-ha headwater basin that is almost all exposed rock. Two of the available three Secchi disk measurements at Dana were greater than 14 m (the end of the line was visible). A third measurement was 9 m.

The chemistry of Dana Lake differs from all others in the network in combining low ANC (16-21 $\mu Eq\ L^{-1}$) with the highest concentrations of calcium, sulfate and nitrate in the network. No statistically-significant temporal trends have been identified for any chemical constituent at Dana, although sulfate has doubled between 2006 and 2009 (Figure 7y), with increasing concentration each year. The 2008-2009 sulfate increase meets the 30% threshold, but because ANC has remained low the sulfate increase is not interpreted to be a cause for alarm. Nitrate at Dana is also high compared to other lakes in the monitoring network. Increases in nitrate between 2006 and 2009 parallel the sulfate increases, but again are not statistically significant through the full monitoring period. Nitrate also increased over 30% from 2008 to 2009, but again without an ANC increase significant concern does not appear justified at this time perhaps because increases in the major cations (calcium, sodium, and potassium) have also occurred at Dana annually since 2006.

Dana Lake's geology differs from that of most of the other lakes in the monitoring network. The geology of the area consists primarily of metamorphic sedimentary and volcanic rocks of the Ritter Range Roof Pendant. The bedrock in the Dana Lake watershed is composed primarily of quartzofeldspathic hornfels, calc-silicate hornfel, and marble and secondarily of volcanic tuffs and flows, lapilli-tuff, and shale (Kistler, 1966a). This strata in the Mono Craters Quadrangle has been informally referred to as the Lewis Sequence (Kistler, 1966b). One of the most common rock types in the Lewis Sequence is a dark pyritic hornfel, presumably derived from a sedimentary rock rich in organic material. Pyrite is an iron sulfide and is found in association with gypsum and anhydrite. Gypsum is frequently interstratified with limestone and shale (Alan Gallegos personal communication). The presence of calcium-bearing mineralogies in particular is atypical of other lakes in the network

Most likely the high sulfate concentration is a natural source that is associated with pyrite. One possibility is that gypsum and anhydrite were inter-bedded with limestone when this material was a sedimentary rock and was metamorphosed into a marble ($CaCO_3$). Pyrite, goethite and limonite are secondary minerals that could have formed from weathering of the existing metamorphic rocks. The marble, gypsum and anhydrite could account for the high calcium (Alan Gallegos, personal communication).

6.0 Water Chemistry Differences between Epilimnion and Hypolimnion Sampling Locations

The sample collection protocol was initially designed to characterize water chemistry in two primary zones of each lake, the shallow zone above any thermocline and the deep zone below any thermocline. Water temperature change was measured throughout the depth of each lake—at a deep "midlake" location—and if a substantial temperature gradient with depth was identified epilimnion and hypolimnion samples were obtained. If a temperature gradient was not identified, only epilimnion samples were collected. Several lakes have never exhibited a temperature gradient and hypolimnion samples are no longer collected from these lakes. The need to continue to collect hypolimnion samples is debatable. The LAKES project now has hypolimnion information at some lakes for seven years (Powell Lake). Continuing hypolimnion sampling could add valuable information but the time and resources needed for hypolimnion sampling may not now be warranted. To better inform a decision on the need for continued hyplimnion sampling the chemistry of major acidification and nitrification indicators are compared below for 36 epilimnion-hypolimnion pairings, from nine lakes.

Graphical comparison of epliminion and hypolimnion concentrations for ANC, calcium, nitrate, and sulfate are shown in Figure 8a-8d. With some notable exceptions, visually the concentration differences between epilimniion and hypolimnion locations are usually minor (although nitrate differences may appear large in Figure 8c, nitrate concentrations are very low compared to the other three constituents and visually relatively minor differences are exaggerated by the scale of the y-axis in Figure 8c). A metric to quantify the difference between the epiliminion and hypolimnion concentrations is the median of the difference between each epilimnion-hypolimnion pairing divided by the median of the entire population of epilimnion and hypolimnion values (the "median difference"). A large median difference would indicate major differences between epilimnion and hypolimnion concentrations (e.g., a median difference = 1.0 indicates that the differences are the same magnitude as the overall median). The median differences for ANC, calcium, nitrate and sulfate respectively are -0.13, -0.15, 0, and -0.005. These median differences are relatively low suggesting relatively close

concurrence between epilimnion and hypolimnion concentrations. Both the graphs and the median difference metrics show that typically epilimnion concentrations are lower than hypolimnion concentrations for all four constituents. This is particularly evident for ANC and calcium, where 30 and 34 of the 36 pairs respectively have lower concentrations in the epilimnion samples.

Exceptions to the general result of relative similarity between epilimnion and hyplimnion concentrations are ANC and calcium at Powell Lake, sulfate at Patterson Lake, and calcium at Long Lake (Figures 8a, b and d). Reasons for the larger differences at these lakes are not known. The ANC and calcium differences at Powell are evident for all seven years of sample collection and the differences are large compared to other lakes (e.g., epilimnion concentrations at Powell are often one-half the magnitude of the hypolimnion samples). Similarly large differences are evident for sulfate at Patterson for some of the years and slightly less evident for calcium at Long. Ceasing collection of hyplimnion samples would end the possibility of further tracking the epliminion-hypolimnion differences at these lakes. However, arguably the current epilimnion-hypolimnion dataset is adequately large to characterize the current status of differences, and those differences for most lakes and for most constituents are relatively low.

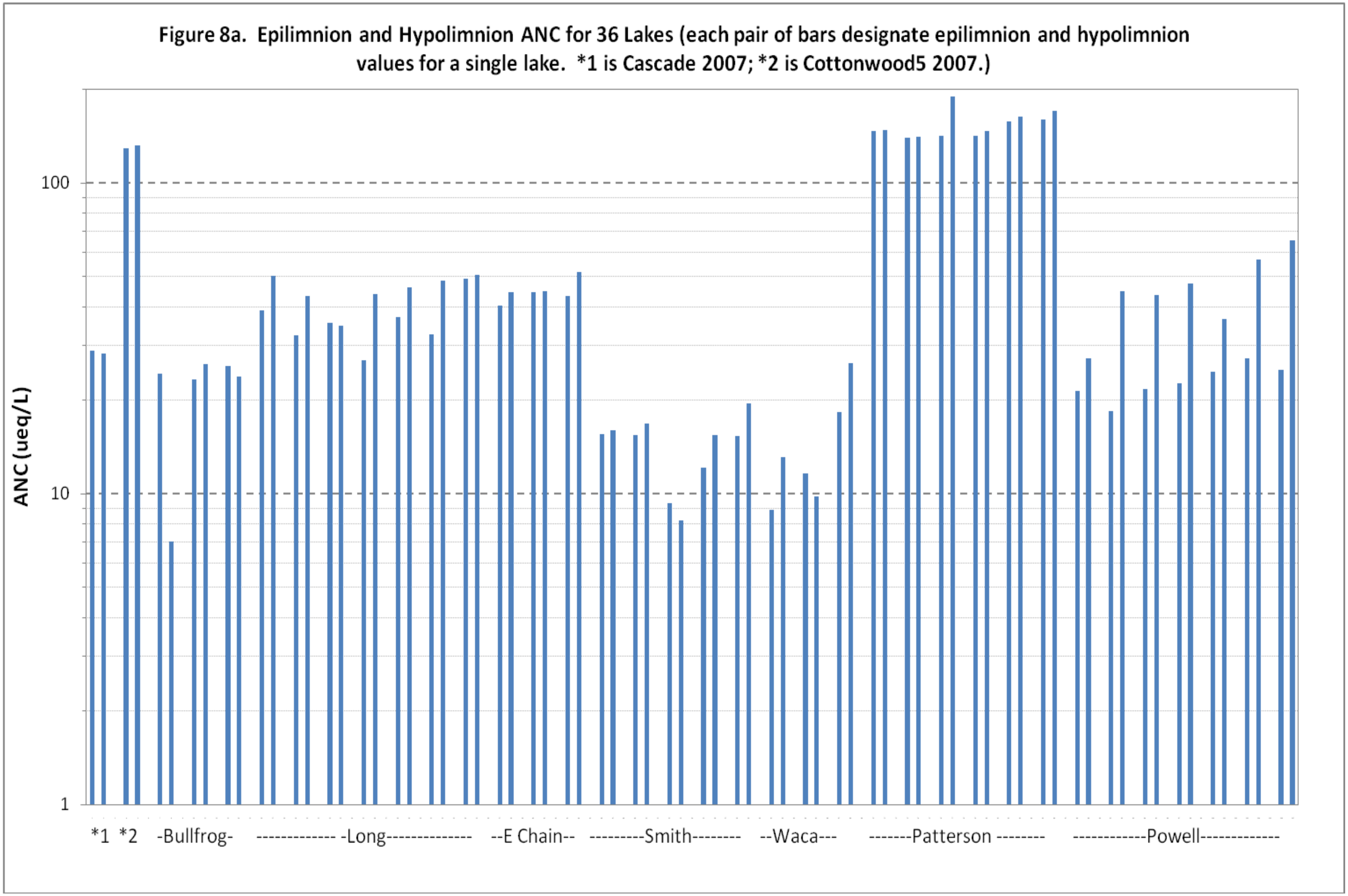


Figure 8a. Epilimnion and Hypolimnion ANC for 36 Lakes (each pair of bars designate epilimnion and hypolimnion values for a single lake. *1 is Cascade 2007; *2 is Cottonwood5 2007.)
ANC (ueq/L)
100
10
1
*1 *2 -Bullfrog- ------------- -Long-------------- --E Chain-- ---------Smith-------- --Waca--- -------Patterson -------- ------------Powell-------------

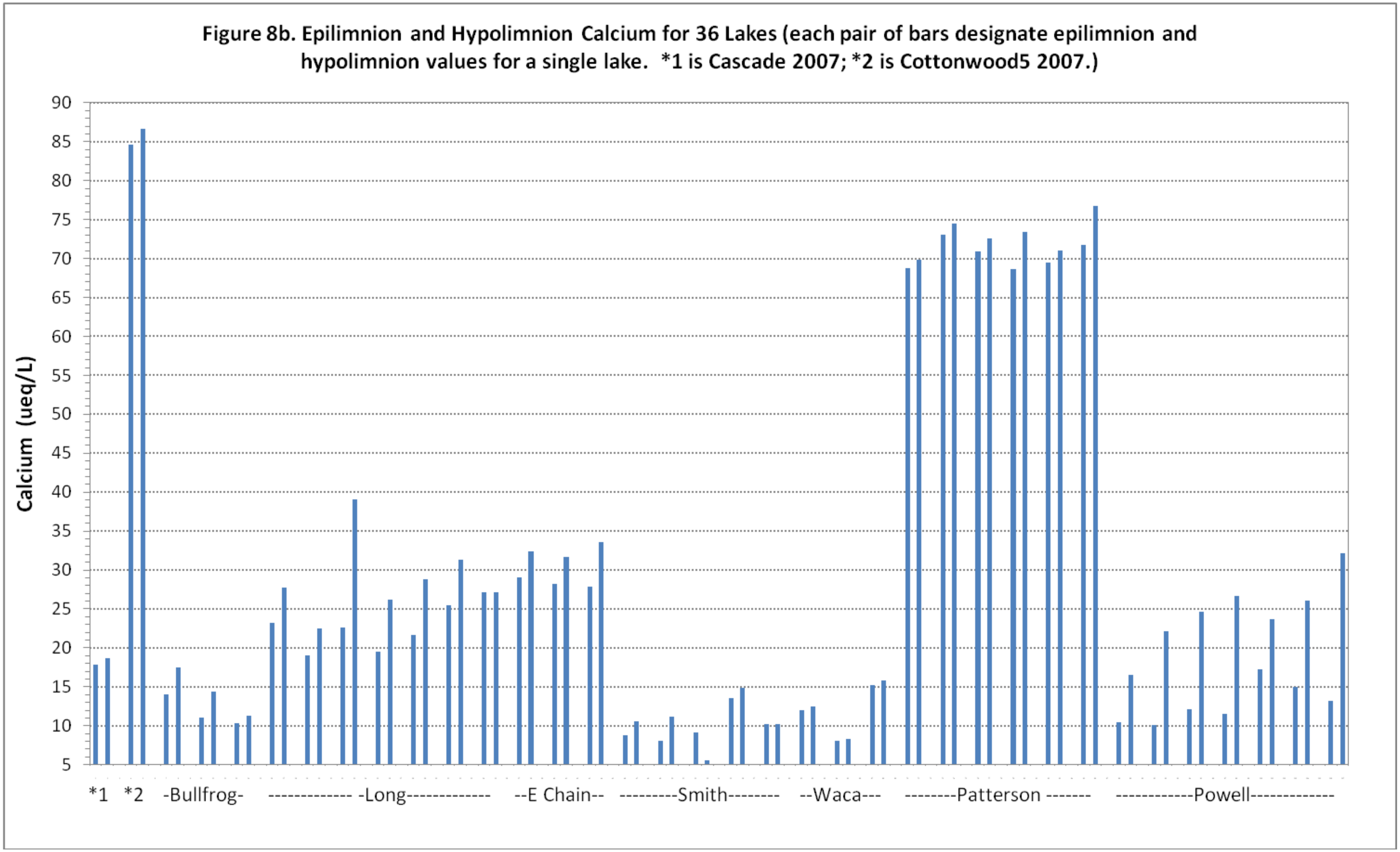


Figure 8b. Epilimnion and Hypolimnion Calcium for 36 Lakes (each pair of bars designate epilimnion and hypolimnion values for a single lake. *1 is Cascade 2007; *2 is Cottonwood5 2007.)
Calcium (ueq/L)
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
*1 *2 -Bullfrog- ------------ -Long------------ --E Chain-- ---------Smith-------- --Waca--- --------Patterson ------- -----------Powell------------

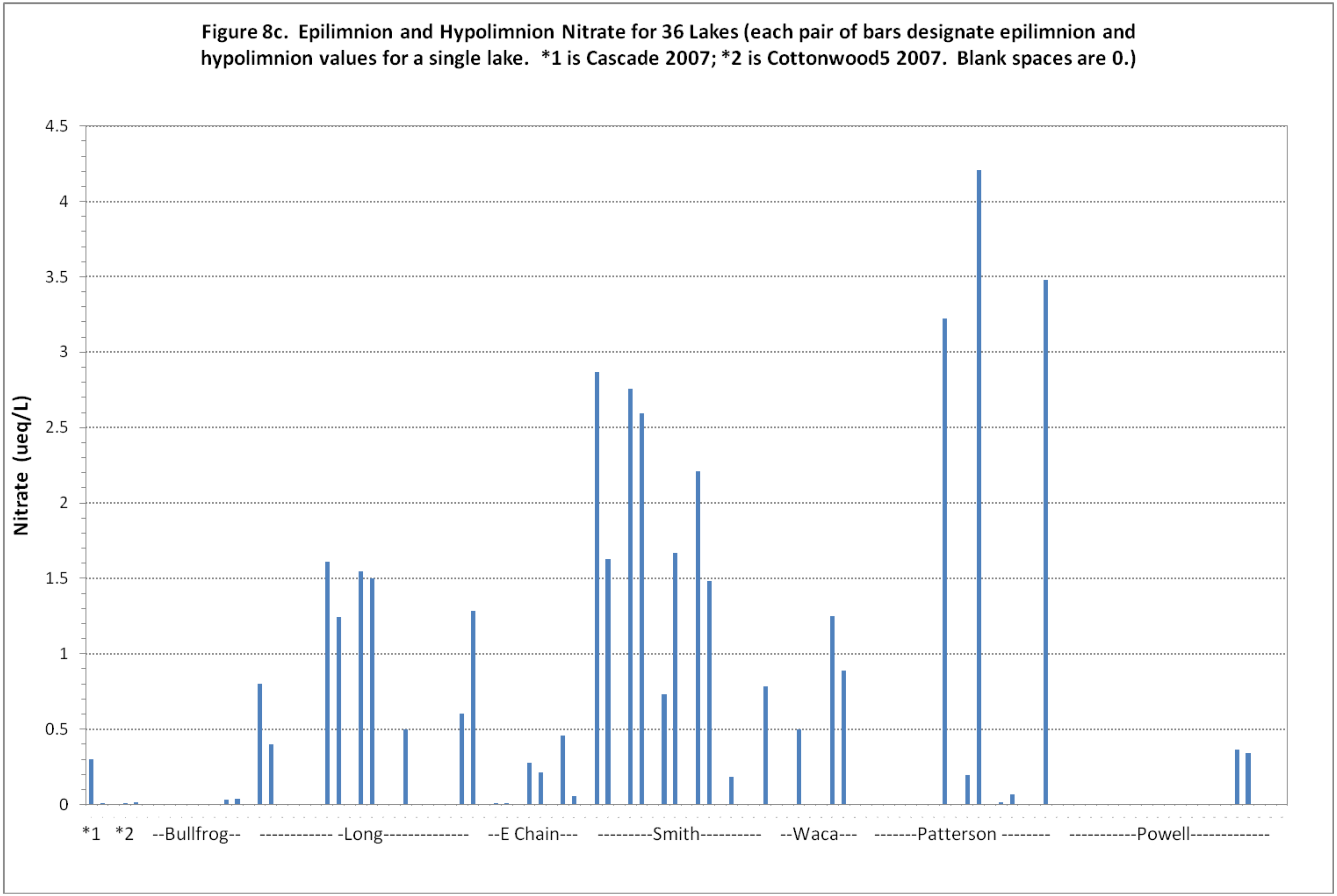


Figure 8c. Epilimnion and Hypolimnion Nitrate for 36 Lakes (each pair of bars designate epilimnion and hypolimnion values for a single lake. *1 is Cascade 2007; *2 is Cottonwood5 2007. Blank spaces are 0.)
Nitrate (ueq/L)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
*1 *2 --Bullfrog-- ------------ -Long-------------- --E Chain--- ---------Smith--------- --Waca--- -------Patterson -------- -----------Powell-------------

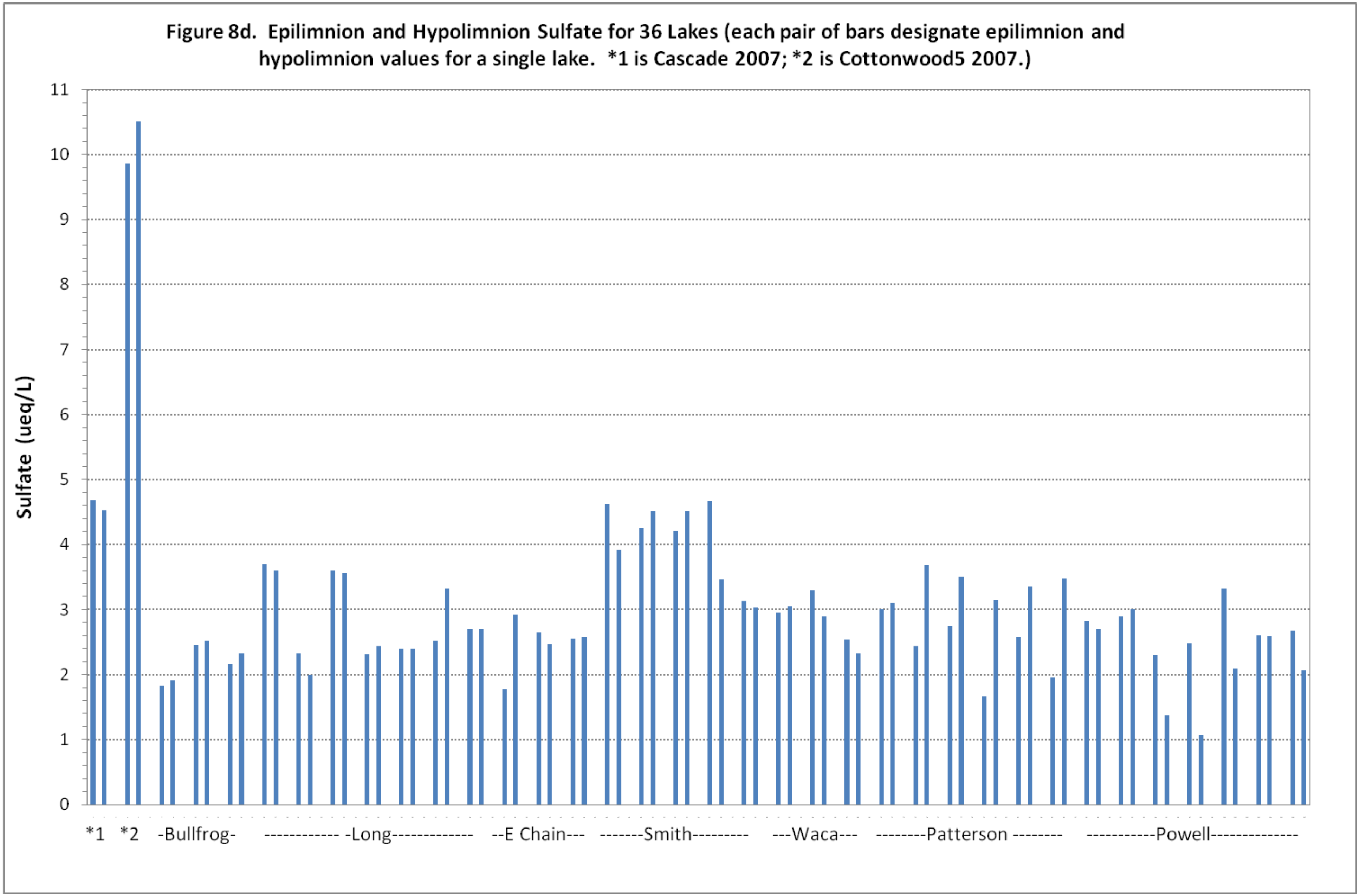


Figure 8d. Epilimnion and Hypolimnion Sulfate for 36 Lakes (each pair of bars designate epilimnion and hypolimnion values for a single lake. *1 is Cascade 2007; *2 is Cottonwood5 2007.)
Sulfate (ueq/L)
0
1
2
3
4
5
6
7
8
9
10
11
*1
*2
-Bullfrog-
----------- -Long------------
--E Chain---
-------Smith--------
---Waca---
--------Patterson --------
----------Powell-------------

7.0 Conclusions

Completion of the network of long-term monitoring lakes in 2007 has extended the ability to identify temporal and spatial trends in lake chemistry changes at twelve Wildernesses—and twenty-two lakes--in the Sierra Nevada and northeastern California.

The 2009 lake monitoring identified no evidence of acidification or nutrification from water chemistry analyses. In contrast, acid neutralizing capacity in 2009 was the highest on record at one-third of the lakes monitored. Nitrate concentrations continue to be low, and non-detectable in several lakes. Between 2008 and 2009 sulfate concentrations increased at about as many lakes as it decreased.

Thirteen lakes were assessed for temporal trends in their acid-base chemistry over the entirety of their records. Although statistically significant changes in lake chemistry were identified at seven lakes, the changes were generally small (usually less than 0.2 $\mu Eq\ L^{-1}\ yr^{-1}$) and not associated with acidification or nutrient buildup. Exceptions included increases in ANC and calcium of nearly 1 $\mu Eq\ L^{-1}\ yr^{-1}$ at two lakes. These increases could indicate increased acid buffering capacity. Statistically significant sulfate decreases at four lakes (up from two lakes in 2008) may also reflect the reductions in sulfur atmospheric deposition documented in many locations in the United States. These trend results are preliminary for most of the lakes and could change as more data are collected.

The sample collection protocol was initially designed to characterize water chemistry in two primary zones of each lake, the shallow zone above any thermocline (the epilimnion) and the deep zone below any thermocline (the hypolimnion). As the LAKES project has matured the need for hyplimnion sampling is under question. To better inform a decision on the need for continued hyplimnion sampling the chemistry of major acidification and nitrification indicators was compared for 36 epilimnion-hypolimnion pairings, from nine lakes. Concentration differences in ANC, calcium, nitrate and sulfate between epilimniion and hypolimnion locations were usually minor, with the median of the differences typically 10% of the median of the epilimnion and hypolimnion concentrations. Also epilimnion concentrations were usually lower than the hypolimnion concentrations, especially for ANC and calcium. Notable exceptions to this generality were at Powell Lake, where ANC and calcium were always appreciably lower in the epilimnion, and at Patterson and Long Lakes where sulfate and calcium respectively were often lower in the epilimnion. Ceasing collection of hyplimnion samples would end the possibility of further tracking the epiliminion-hypolimnion differences. However, arguably the current epilimnion-hypolimnion dataset is adequately large to characterize the current status of differences, and those differences for most lakes and for most constituents are relatively low.

The overall quality of the 2009 laboratory analysis was above “average” compared to prior years. In some prior years minor irregularities were identified. In 2009 there were none. Continued vigilance in field sample collection and laboratory procedures is recommended to help assure continued high quality data.

Acknowledgements

This report benefited substantially from data provided by Sharon Grant and from chemical analyses performed by the Air Resource Management Laboratory, Ft. Collins. Sample collection by numerous, unnamed individuals allows this program to succeed.

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Appendix I. 2009 Chemistry Results from USDA Forest Service Region 5 Air Program Wilderness Lake Monitoring

LAB ID	FIELD ID	LAKE NAME	WILDERNESS	MILITARY TIME	SAMPLE DATE	RECEIVE DATE
09ST3706	15KA09-E1	Long	Kaiser	1145	06/12/09	06/16/09
09ST3708	15KA09-S1	Long	Kaiser	1250	06/12/09	06/16/09
09ST3707	15KA09-E2	Long	Kaiser	1145	06/12/09	06/17/09
09ST3709	15KA09-S2	Long	Kaiser	1255	06/12/09	06/17/09
09ST3710	15DL015-E1	Bullfrog	Dinky	1527	06/16/09	06/19/09
09ST3711	15DL015-E2	Bullfrog	Dinky	1522	06/16/09	06/23/09
09ST3712	15JM345-E1	East Chain	John Muir	1508	06/18/09	06/23/09
09ST3714	15JM345-H1	East Chain	John Muir	1520	06/18/09	06/23/09
09ST3713	15JM345-E2	East Chain	John Muir	1511	06/18/09	06/24/09
09ST3715	15JM345-H2	East Chain	John Muir	1527	06/18/09	06/24/09
09ST3717	15JM037-E1	Vermilion	John Muir	1414	06/25/09	07/01/09
09ST3718	15JM037-E2	Vermilion	John Muir	1417	06/25/09	07/02/09
09ST3679	06CB08-E1	Caribou #8	Caribou	1343	06/29/09	07/02/09
09ST3678	06CB08-E2	Caribou #8 Duplicate	Caribou	1348	06/29/09	07/02/09
09ST3719	15AA090-S1	Walton	Ansel Adams	1405	06/30/09	07/07/09
09ST3660	06TL06-S1	Hufford	Thousand Lakes	1119	07/01/09	07/07/09
09ST3661	06TL06-S2	Hufford	Thousand Lakes	1125	07/01/09	07/07/09
09ST3500	15AA090-S2	Walton Duplicate	Ansel Adams	1407	06/30/09	07/07/09
09ST3740	16EM47-1E	Powell	Emigrant	1226	07/08/09	07/10/09
09ST3741	16EM47-2E	Powell Duplicate	Emigrant	1228	07/08/09	07/10/09
09ST3742	16EM47-1H	Powell	Emigrant	1238	07/08/09	07/10/09
09ST3743	16EM47-2H	Powell Duplicate	Emigrant	1245	07/08/09	07/10/09
09ST3744	16EM47-1S	Powell	Emigrant	1400	07/08/09	07/10/09
09ST3745	16EM47-2S	Powell Duplicate	Emigrant	1401	07/08/09	07/10/09
09ST3543	03DE03-2E	Waca	Desolation	1400	07/08/09	07/14/09
09ST3544	03DE03-1E	Waca	Desolation	1400	07/08/09	07/14/09
09ST3738	16EM27-S1	Karls	Emigrant	734	07/14/09	07/17/09
09ST3739	16EM27-S2	Karls	Emigrant	736	07/14/09	07/17/09
09ST3545	03DE02-E1	Smith	Desolation	1220	07/15/09	07/17/09
09ST3546	03DE02-H1	Smith	Desolation	1200	07/15/09	07/17/09
09ST3547	03DE02-H2	Smith	Desolation	1215	07/15/09	07/17/09
09ST3549	03DE02-E2	Smith	Desolation	1225	07/15/09	07/17/09
09ST3580	04JM024-E1	Treasure	John Muir	1150	07/15/09	07/17/09
09ST3581	04JM194-E2	Bench	John Muir	1118	07/15/09	07/17/09
09ST3582	04JM024-1S	Treasure	John Muir	1133	07/15/09	07/17/09
09ST3583	04JM024-2S	Treasure	John Muir	1130	07/15/09	07/17/09
09ST3585	04JM024-E2	Treasure	John Muir	1153	07/14/09	07/17/09
09ST3746	16EM28-1S	Key Lake	Emigrant	1346	07/15/09	07/17/09
09ST3747	16EM28-2S	Key Lake	Emigrant	1348	07/15/09	07/17/09
09ST3584	04JM194-E1	Bench	John Muir	1115	07/14/09	07/17/09
09ST3550	03MK14-1E	Moke 14	Mokelumne	1620	07/21/09	07/24/09
09ST3551	03MK19-2E	Lower Cole Ck	Mokelumne	1045	07/22/09	07/24/09
09ST3552	03MK14-2E	Moke 14	Mokelumne	1623	07/21/09	07/24/09
09ST3553	03MK19-1E	Lower Cole Ck	Mokelumne	1045	07/22/09	07/24/09
09ST3586	15JM292-E1	Wahoo East	John Muir	914	07/21/09	07/24/09
09ST3587	15JM292-E2	Wahoo East	John Muir	916	07/21/09	07/24/09
09ST3600	04HOO40-E1	Cascade	Hoover	957	07/22/09	07/24/09

LAB ID	FIELD ID	LAKE NAME	WILDERNESS	MILITARY TIME	SAMPLE DATE	RECEIVE DATE
09ST3601	04HOO40-E2	Cascade	Hoover	959	07/22/09	07/24/09
09ST3602	04HOO40-S1	Cascade	Hoover	1007	07/22/09	07/24/09
09ST3603	04HOO40-S2	Cascade	Hoover	1009	07/22/09	07/24/09
09ST3640	17HOO04-1S	Moat (shoreline)	Hoover	1052	07/22/09	07/24/09
09ST3641	17HOO04-2S	Moat (shoreline)	Hoover	1058	07/22/09	07/24/09
09ST3642	17HOO04-E1	Moat (mid-lake)	Hoover	1136	07/22/09	07/24/09
09ST3643	17HOO04-E2	Moat (mid-lake)	Hoover	1146	07/22/09	07/24/09
09ST3589	AA04001-S2	Dana Duplicate	Ansel Adams	1337	07/23/09	07/28/09
09ST3590	AA04001-S1	Dana	Ansel Adams	1333	07/23/09	07/28/09
09ST3604	04AA132-E1	Little East Marie	Ansel Adams	1749	07/24/09	07/29/09
09ST3605	04AA132-E2	Little East Marie	Ansel Adams	1755	07/24/09	07/29/09
ST150	16EM47-S1	Powell	Emigrant	1503	09/19/09	09/23/09
ST151	16EM47-S2	Powell Duplicate	Emigrant	1505	09/19/09	09/23/09
09ST3591	04HO40-1S	Cascade	Hoover	1345	09/28/09	10/01/09
09ST3592	04HO40-2S	Cascade	Hoover	1355	09/28/09	10/01/09
09ST3593	04JM024-1S	Treasure	John Muir	1245	09/29/09	10/01/09
09ST3594	04JM024-2S	Treasure	John Muir	1300	09/29/09	10/01/09
Field Blanks						
09ST3716	15JM345-FB	East Chain	John Muir		06/18/09	06/23/09
09ST3677	06CB08-FB	Caribou #8	Caribou		06/29/09	07/02/09
09ST3662	06TL06FB	Hubbard	Thousand Lakes		07/01/09	07/07/09
09ST3540	03DE03-FB	Waca	Desolation		07/08/09	07/14/09
09ST3548	03DE02-FB	Smith	Desolation		07/15/09	07/17/09
09ST3554	03MK19-FB	Lower Cole Ck	Mokelumne		07/22/09	07/24/09
09ST3588	15JM292FB	Wahoo East	John Muir		07/21/09	07/24/09

LAKE NAME	pH	uE/L ANC	uS/cm Conduct.	mg/l Na	mg/l NH4	mg/l K	mg/l Mg
Long	6.46	45.3	5.35	0.51	0.02	0.20	0.06
Long	6.44	44.6	5.29	0.51	0.02	0.22	0.05
Long	6.39	45.3	5.25	0.51	0.01	0.19	0.06
Long	6.52	47.5	5.36	0.51	0.02	0.20	0.06
Bullfrog	6.04	23.4	3.80	0.46	0.00	0.17	0.05
Bullfrog	6.02	24.5	3.77	0.45	0.00	0.12	0.05
East Chain	6.41	44.3	5.09	0.48	0.00	0.19	0.05
East Chain	6.35	52.1	5.79	0.50	0.00	0.17	0.05
East Chain	6.50	42.59	5.65	0.48	0.00	0.18	0.05
East Chain	6.43	51.34	6.23	0.50	0.00	0.21	0.06
Vermilion	6.47	42.08	5.05	0.70	0.00	0.19	0.04
Vermilion	6.61	42.89	5.11	0.73	0.00	0.18	0.05
Caribou #8	6.25	29.75	3.99	0.20	0.01	0.08	0.27
Caribou #8 Duplicate	6.26	33.4	3.93	0.20	0.02	0.07	0.26
Walton	5.96	17.6	3.43	0.15	0.00	0.08	0.02
Hufford	6.61	45.41	5.23	0.33	0.01	0.12	0.15
Hufford	6.63	46.21	5.26	0.33	0.01	0.12	0.17
Walton Duplicate	5.92	17.18	3.62	0.17	0.00	0.11	0.03
Powell	6.19	21.5	3.61	0.40	0.00	0.15	0.07
Powell Duplicate	6.18	28.7	3.57	0.40	0.00	0.11	0.07
Powell	5.89	64.7	8.04	0.58	0.00	0.32	0.16
Powell Duplicate	5.91	65.7	8.49	0.59	0.00	0.30	0.18
Powell	6.26	30.1	3.64	0.40	0.00	0.14	0.06
Powell Duplicate	6.24	24.9	3.45	0.40	0.00	0.12	0.06
Waca	6.15	23.5	2.96	0.13	0.00	0.12	0.04
Waca	6.13	22.5	2.92	0.13	0.00	0.11	0.04
Karls	6.06	15.25	3.08	0.21	0.01	0.11	0.05
Karls	6.04	15.88	3.05	0.21	0.02	0.10	0.07
Smith	6.35	14.24	3.06	0.30	0.01	0.08	0.03
Smith	6.47	20.68	3.13	0.32	0.01	0.09	0.04
Smith	6.48	18.32	3.24	0.32	0.01	0.09	0.04
Smith	6.35	16.51	2.96	0.30	0.00	0.08	0.03
Treasure	6.73	32.26	5.26	0.24	0.01	0.18	0.04
Bench	7.04	73.61	12.25	0.73	0.00	0.11	0.08
Treasure	6.74	36.42	5.34	0.22	0.01	0.15	0.04
Treasure	6.72	33.59	5.15	0.23	0.01	0.16	0.04
Treasure	6.74	35.31	5.27	0.22	0.01	0.15	0.04
Key Lake	5.93	7.8	1.82	0.10	0.03	0.07	0.03
Key Lake	5.93	5.93	1.85	0.10	0.03	0.05	0.03
Bench	7.00	69.83	12.72	0.72	0.00	0.11	0.08
Moke 14	5.91	24.69	4.55	0.55	0.00	0.14	0.07
Lower Cole Ck	6.27	37.72	5.45	0.44	0.00	0.18	0.09
Moke 14	5.98	23.08	4.81	0.48	0.01	0.18	0.08
Lower Cole Ck	6.29	38.66	5.26	0.44	0.00	0.16	0.09
Wahoo East	7.04	69.86	8.19	0.43	0.01	0.20	0.04
Wahoo East	7.05	74.72	7.70	0.48	0.00	0.20	0.04
Cascade	6.56	24.28	3.47	0.37	0.00	0.11	0.03

LAKE NAME	pH	uE/L ANC	uS/cm Conduct.	mg/l Na	mg/l NH4	mg/l K	mg/l Mg
Cascade	6.51	31.22	3.54	0.37	0.00	0.12	0.03
Cascade	6.48	26.99	3.54	0.37	0.00	0.11	0.03
Cascade	6.52	33.4	3.46	0.33	0.01	0.10	0.03
Moat (shoreline)	7.02	62.2	8.29	0.54	0.00	0.23	0.08
Moat (shoreline)	6.94	59.5	8.48	0.58	0.00	0.28	0.08
Moat (mid-lake)	7.06	62.41	8.47	0.56	0.00	0.25	0.09
Moat (mid-lake)	7.06	60.86	8.56	0.55	0.00	0.23	0.08
Dana Duplicate	6.14	23.121	19.48	0.41	0.00	0.30	0.24
Dana	6.25	19.603	19.75	0.41	0.00	0.28	0.25
Little East Marie	6.26	22.25	4.83	0.19	0.00	0.12	0.05
Little East Marie	6.28	18.5	4.66	0.18	0.00	0.12	0.05
Powell	6.32	26.01	4.05	0.54	0.00	0.18	0.07
Powell Duplicate	6.35	27.64	3.91	0.50	0.00	0.22	0.07
Cascade	6.73	51.18	5.13	0.72	0.00	0.13	0.05
Cascade	6.71	51.66	4.96	0.71	0.00	0.14	0.04
Treasure	6.82	52.36	5.28	0.36	0.00	0.21	0.05
Treasure	6.88	54.5	5.38	0.36	0.00	0.23	0.05
East Chain	5.37	-6.4	1.59	0.00	0.01	0.00	0.01
Caribou #8	5.44	0.9	1.65		0.01	0.00	0.00
Hubbard	5.47	1.87	1.39	0.00	0.02	0.00	0.00
Waca	5.49	5.5	1.81	0.00	0.03	0.00	0.00
Smith	5.58	5.42	1.37	0.00	0.02	0.00	0.00
Lower Cole Ck	5.49	5.84	1.49	0.00	0.00	0.02	0.00
Wahoo East	5.53	6.92	1.29	0.00	0.01	0.00	0.00

LAKE NAME	mg/l Ca	mg/l F	mg/l Cl	mg/l NO2	mg/l NO3	mg/l PO4	mg/l SO4	ueq/L ANC
Long	0.47	0.006	0.07	0.00	0.00	0.01	0.10	45.3
Long	0.46	0.006	0.08	0.00	0.00	0.00	0.12	44.6
Long	0.48	0.006	0.08	0.04	0.00	0.00	0.13	45.3
Long	0.48	0.006	0.09	0.00	0.00	0.00	0.14	47.5
Bullfrog	0.23	0.000	0.08	0.05	0.00	0.00	0.11	23.4
Bullfrog	0.27	0.000	0.05	0.00	0.00	0.00	0.05	24.5
East Chain	0.53	0.004	0.07	0.03	0.02	0.01	0.09	44.3
East Chain	0.69	0.005	0.08	0.04	0.01	0.00	0.11	52.1
East Chain	0.58	0.011	0.07	0.00	0.04	0.00	0.16	42.6
East Chain	0.66	0.005	0.09	0.08	0.00	0.00	0.14	51.3
Vermilion	0.30	0.004	0.07	0.00	0.00	0.00	0.21	42.1
Vermilion	0.32	0.005	0.07	0.07	0.00	0.00	0.21	42.9
Caribou #8	0.14	0.000	0.09	0.08	0.00	0.00	0.04	29.8
Caribou #8 Duplicate	0.14	0.000	0.09	0.07	0.00	0.00	0.04	33.4
Walton	0.33	0.005	0.04	0.08	0.37	0.00	0.29	17.6
Hufford	0.45	0.000	0.20	0.00	0.00	0.00	0.08	45.4
Hufford	0.46	0.000	0.19	0.07	0.00	0.00	0.10	46.2
Walton Duplicate	0.29	0.005	0.04	0.00	0.36	0.00	0.28	17.2
Powell	0.28	0.001	0.10	0.00	0.00	0.00	0.13	21.5
Powell Duplicate	0.25	0.001	0.10	0.00	0.00	0.00	0.13	28.7
Powell	0.64	0.003	0.26	0.00	0.00	0.00	0.10	64.7
Powell Duplicate	0.65	0.004	0.27	0.00	0.00	0.00	0.10	65.7
Powell	0.24	0.001	0.10	0.00	0.00	0.00	0.12	30.1
Powell Duplicate	0.21	0.001	0.10	0.00	0.00	0.00	0.13	24.9
Waca	0.23	0.000	0.08	0.00	0.02	0.00	0.10	23.5
Waca	0.21	0.000	0.08	0.00	0.02	0.00	0.11	22.5
Karls	0.22	0.001	0.03	0.00	0.00	0.00	0.11	15.3
Karls	0.23	0.000	0.08	0.00	0.00	0.00	0.04	15.9
Smith	0.20	0.000	0.09	0.00	0.00	0.00	0.15	14.2
Smith	0.20	0.000	0.11	0.00	0.00	0.00	0.14	20.7
Smith	0.21	0.000	0.11	0.00	0.00	0.00	0.15	18.3
Smith	0.21	0.000	0.09	0.00	0.02	0.00	0.15	16.5
Treasure	0.69	0.004	0.08	0.01	0.44	0.00	0.23	32.3
Bench	1.68	0.021	0.14	0.00	1.47	0.01	0.87	73.6
Treasure	0.68	0.005	0.07	0.01	0.45	0.00	0.27	36.4
Treasure	0.66	0.004	0.07	0.01	0.41	0.00	0.24	33.6
Treasure	0.69	0.005	0.07	0.00	0.43	0.00	0.26	35.3
Key Lake	0.16	0.000	0.11	0.00	0.00	0.00	0.14	7.8
Key Lake	0.14	0.000	0.11	0.00	0.00	0.00	0.15	5.9
Bench	1.62	0.021	0.14	0.00	1.47	0.00	0.92	69.8
Moke 14	0.27	0.000	0.06	0.00	0.01	0.00	0.21	24.7
Lower Cole Ck	0.44	0.000	0.08	0.00	0.00	0.02	0.02	37.7
Moke 14	0.19	0.000	0.11	0.00	0.00	0.00	0.02	23.1
Lower Cole Ck	0.49	0.000	0.11	0.00	0.00	0.00	0.02	38.7
Wahoo East	1.08	0.002	0.06	0.00	0.00	0.00	0.23	69.9
Wahoo East	1.05	0.002	0.05	0.00	0.00	0.00	0.16	74.7
Cascade	0.36	0.000	0.03	0.00	0.00	0.00	0.09	24.3

LAKE NAME	mg/l Ca	mg/l F	mg/l Cl	mg/l NO2	mg/l NO3	mg/l PO4	mg/l SO4	ueq/L ANC
Cascade	0.34	0.000	0.03	0.00	0.00	0.00	0.11	31.2
Cascade	0.32	0.000	0.03	0.00	0.00	0.00	0.12	27.0
Cascade	0.34	0.000	0.04	0.00	0.00	0.00	0.12	33.4
Moat (shoreline)	1.01	0.000	0.07	0.00	0.00	0.00	0.70	62.2
Moat (shoreline)	1.02	0.000	0.11	0.00	0.00	0.00	0.77	59.5
Moat (mid-lake)	1.08	0.000	0.09	0.00	0.00	0.00	0.78	62.4
Moat (mid-lake)	1.06	0.004	0.08	0.00	0.00	0.00	0.55	60.9
Dana Duplicate	2.40	0.011	0.09	0.00	1.11	0.00	6.23	23.1
Dana	2.45	0.011	0.09	0.00	1.10	0.00	6.27	19.6
Little East Marie	0.46	0.000	0.02	0.00	0.06	0.01	0.34	22.3
Little East Marie	0.45	0.000	0.03	0.00	0.06	0.00	0.15	18.5
Powell	0.25	0.010	0.15	0.00	0.00	0.00	0.12	26.0
Powell Duplicate	0.23	0.010	0.15	0.00	0.00	0.00	0.12	27.6
Cascade	0.56	0.020	0.05	0.00	0.00	0.00	0.20	51.2
Cascade	0.57	0.019	0.04	0.00	0.00	0.00	0.21	51.7
Treasure	0.81	0.014	0.06	0.00	0.00	0.01	0.17	52.4
Treasure	0.80	0.015	0.06	0.00	0.00	0.00	0.20	54.5
East Chain	0.04	0.000	0.00	0.05	0.00	0.00	0.01	-6.4
Caribou #8	0.02	0.000	0.01	0.07	0.00	0.00	0.01	0.9
Hubbard	0.03	0.000	0.01	0.07	0.00	0.00	0.00	1.9
Waca	0.02	0.000	0.01	0.00	0.00	0.00	0.01	5.5
Smith	0.03	0.000	0.02	0.00	0.00	0.00	0.01	5.4
Lower Cole Ck	0.03	0.000	0.12	0.00	0.00	0.00	0.02	5.8
Wahoo East	0.02	0.000	0.00	0.00	0.00	0.00	0.01	6.9

LAKE NAME	ueq/L H	ueq/L Ca	ueq/L Mg	ueq/L Na	ueq/L K	ueq/L NH4	ueq/L F
Long	0.35	23.4	4.6	22.0	5.2	1.33	0.32
Long	0.37	23.0	4.4	22.0	5.6	1.28	0.32
Long	0.41	24.0	4.7	22.0	4.9	0.72	0.32
Long	0.30	23.8	4.7	22.4	5.1	1.28	0.32
Bullfrog	0.92	11.6	4.3	19.9	4.3	0.00	0.00
Bullfrog	0.95	13.6	4.4	19.7	3.1	0.00	0.00
East Chain	0.39	26.6	3.9	21.1	4.8	0.00	0.21
East Chain	0.45	34.2	4.2	21.9	4.5	0.00	0.26
East Chain	0.32	29.0	3.9	20.8	4.7	0.00	0.58
East Chain	0.37	33.0	4.6	21.8	5.4	0.00	0.26
Vermilion	0.34	14.8	3.1	30.6	4.8	0.00	0.21
Vermilion	0.25	15.9	3.7	31.6	4.7	0.00	0.26
Caribou #8	0.57	7.0	21.8	8.5	2.1	0.44	0.00
Caribou #8 Duplicate	0.55	7.0	21.7	8.8	1.9	0.83	0.00
Walton	1.10	16.4	1.9	6.5	2.1	0.11	0.26
Hufford	0.25	22.2	12.3	14.4	2.9	0.39	0.00
Hufford	0.23	22.9	14.2	14.3	3.2	0.78	0.00
Walton Duplicate	1.20	14.5	2.6	7.3		0.00	0.26
Powell	0.65	13.7	5.4	17.4	3.8	0.00	0.05
Powell Duplicate	0.66	12.7	5.5	17.5	2.8	0.00	0.05
Powell	1.28	32.0	13.5	25.4	8.1	0.00	0.16
Powell Duplicate	1.24	32.3	14.4	25.6	7.7	0.00	0.21
Powell	0.54	12.0	5.1	17.3	3.6	0.00	0.05
Powell Duplicate	0.58	10.6	5.0	17.5	2.9	0.00	0.05
Waca	0.70	11.3	3.3	5.4	3.0	0.17	0.00
Waca	0.73	10.3	3.2	5.6	2.9	0.22	0.00
Karls	0.87	11.2	4.4	9.1	2.9	0.61	0.05
Karls	0.91	11.3	5.6	9.0	2.6	1.00	0.00
Smith	0.45	10.2	2.7	13.0	1.9	0.44	0.00
Smith	0.34	10.0	3.1	14.0	2.3	0.72	0.00
Smith	0.33	10.5	2.9	14.0	2.4	0.78	0.00
Smith	0.45	10.2	2.6	13.0	2.0	0.17	0.00
Treasure	0.18	34.4	3.5	10.4	4.5	0.33	0.21
Bench	0.09	84.0	6.6	31.5	2.8	0.00	1.11
Treasure	0.18	33.9	3.1	9.7	3.9	0.44	0.26
Treasure	0.19	33.1	3.0	10.1	4.1	0.72	0.21
Treasure	0.18	34.6	3.5	9.7	3.8	0.61	0.26
Key Lake	1.17	8.1	2.5	4.4	1.7	1.50	0.00
Key Lake	1.18	6.9	2.5	4.3	1.4	1.66	0.00
Bench	0.10	81.0	6.3	31.1	2.9	0.00	1.11
Moke 14	1.24	13.5	5.5	24.0	3.6	0.00	0.00
Lower Cole Ck	0.53	22.1	7.7	19.0	4.6	0.00	0.00
Moke 14	1.06	9.4	6.2	20.7	4.6	0.78	0.00
Lower Cole Ck	0.51	24.7	7.5	19.2	4.1	0.00	0.00
Wahoo East	0.09	53.7	3.3	18.7	5.1	0.50	0.11
Wahoo East	0.09	52.5	3.4	20.7	5.1	0.00	0.11
Cascade	0.28	17.7	2.3	16.0	2.7	0.00	0.00

LAKE NAME	ueq/L pH	ueq/L Ca	ueq/L Mg	ueq/L Na	ueq/L K	ueq/L NH4	ueq/L F
Cascade	0.31	16.9	2.5	16.3	2.9	0.00	0.00
Cascade	0.33	15.7	2.3	16.3	2.7	0.00	0.00
Cascade	0.30	16.9	2.1	14.2	2.7	0.28	0.00
Moat (shoreline)	0.10	50.3	6.3	23.3	5.8	0.00	0.00
Moat (shoreline)	0.12	51.1	6.8	25.3	7.1	0.00	0.00
Moat (mid-lake)	0.09	53.9	7.1	24.4	6.3	0.00	0.00
Moat (mid-lake)	0.09	52.9	6.2	23.8	6.0	0.00	0.21
Dana Duplicate	0.72	119.9	20.1	17.9	7.5	0.00	0.58
Dana	0.57	122.3	20.2	17.8	7.1	0.00	0.58
Little East Marie	0.55	22.8	3.8	8.3	3.1	0.00	0.00
Little East Marie	0.52	22.5	3.8	8.0	3.1	0.00	0.00
Powell	0.48	12.4	5.4	23.4	4.7	0.00	0.53
Powell Duplicate	0.45	11.4	5.8	21.9	5.7	0.00	0.53
Cascade	0.19	27.8	3.8	31.3	3.4	0.00	1.05
Cascade	0.19	28.3	3.4	30.9	3.6	0.00	1.00
Treasure	0.15	40.5	3.9	15.6	5.5	0.00	0.74
Treasure	0.13	40.0	4.4	15.6	5.8	0.00	0.79
East Chain	4.24	2.1	1.2	0.0	0.0	0.61	0.00
Caribou #8	3.66	1.1	0.0	0.0	0.0	0.39	0.00
Hubbard	3.39	1.3	0.0	0.0	0.0	0.89	0.00
Waca	3.24	0.9	0.0	0.0	0.0	1.44	0.00
Smith	2.65	1.4	0.0	0.0	0.0	0.94	0.00
Lower Cole Ck	3.24	1.6	0.0	0.0	0.5	0.17	0.00
Wahoo East	2.96	1.0	0.0	0.0	0.0	0.44	0.00

LAKE NAME	ueq/L CL	ueq/L NO2	ueq/L NO3	ueq/L SO4	ueq/L [ANC]	SUM ANIONS	SUM CATIONS	TOTAL ION	%ION DIFF
Long	2.06	0.00	0.00	2.08	45.3	49.8	56.9	106.6	-6.6
Long	2.34	0.00	0.02	2.56	44.6	49.8	56.6	106.4	-6.4
Long	2.26	0.91	0.03	2.64	45.3	50.6	56.6	107.2	-5.7
Long	2.43	0.00	0.02	2.81	47.5	53.1	57.6	110.7	-4.0
Bullfrog	2.26	1.00	0.02	2.19	23.4	27.9	41.0	68.9	-19.0
Bullfrog	1.52	0.00	0.02	1.10	24.5	27.1	41.8	68.9	-21.3
East Chain	1.95	0.63	0.29	1.83	44.3	48.6	56.7	105.2	-7.7
East Chain	2.23	0.83	0.11	2.19	52.1	56.9	65.2	122.1	-6.9
East Chain	2.03	0.00	0.63	3.27	42.6	49.1	58.9	107.9	-9.0
East Chain	2.48	1.72	0.00	2.96	51.3	57.0	65.2	122.3	-6.7
Vermilion	1.86	0.00	0.00	4.41	42.1	48.6	53.7	102.2	-5.0
Vermilion	1.86	1.52	0.03	4.43	42.9	49.5	56.2	105.6	-6.3
Caribou #8	2.43	1.70	0.00	0.73	29.8	32.9	40.5	73.4	-10.3
Caribou #8 Duplicate	2.45	1.43	0.00	0.73	33.4	36.6	40.9	77.4	-5.5
Walton	1.18	1.72	5.95	6.06	17.6	31.1	28.1	59.2	5.0
Hufford	5.64	0.00	0.00	1.71	45.4	52.8	52.5	105.2	0.3
Hufford	5.27	1.41	0.02	2.02	46.2	53.5	55.5	109.0	-1.8
Walton Duplicate	1.16	0.00	5.85	5.83	17.2	30.3	25.5	55.8	8.5
Powell	2.76	0.02	0.00	2.64	21.5	27.0	40.9	67.9	-20.5
Powell Duplicate	2.93	0.04	0.00	2.71	28.7	34.4	39.1	73.5	-6.4
Powell	7.31	0.02	0.00	2.08	64.7	74.2	80.3	154.5	-3.9
Powell Duplicate	7.53	0.02	0.00	2.04	65.7	75.5	81.2	156.6	-3.7
Powell	2.74	0.04	0.00	2.58	30.1	35.4	38.5	74.0	-4.2
Powell Duplicate	2.85	0.02	0.00	2.60	24.9	30.4	36.7	67.1	-9.3
Waca	2.17	0.04	0.24	2.12	23.5	28.1	23.9	52.0	8.0
Waca	2.28	0.02	0.24	2.29	22.5	27.3	23.0	50.3	8.7
Karls	0.96	0.02	0.00	2.21	15.3	18.5	29.1	47.6	-22.4
Karls	2.14	0.00	0.00	0.87	15.9	18.9	30.5	49.4	-23.5
Smith	2.65	0.04	0.00	3.12	14.2	20.0	28.7	48.7	-17.9
Smith	3.02	0.04	0.00	2.94	20.7	26.6	30.4	57.1	-6.6
Smith	3.13	0.02	0.00	3.12	18.3	24.6	30.9	55.5	-11.5
Smith	2.65	0.07	0.37	3.12	16.5	22.7	28.6	51.2	-11.6
Treasure	2.34	0.17	7.14	4.79	32.3	46.7	53.2	99.9	-6.4
Bench	3.95	0.00	23.63	18.18	73.6	120.5	125.0	245.5	-1.9
Treasure	1.92	0.17	7.27	5.54	36.4	51.4	51.3	102.8	0.1
Treasure	2.06	0.15	6.66	5.06	33.6	47.6	51.2	98.8	-3.7
Treasure	1.92	0.00	6.90	5.35	35.3	49.7	52.4	102.1	-2.6
Key Lake	3.02	0.04	0.00	2.94	7.8	13.8	19.3	33.1	-16.8
Key Lake	3.13	0.02	0.00	3.12	5.9	12.2	17.9	30.1	-19.0
Bench	3.92	0.00	23.72	19.22	69.8	117.8	121.5	239.3	-1.6
Moke 14	1.61	0.04	0.16	4.29	24.7	30.7	47.9	78.7	-21.8
Lower Cole Ck	2.12	0.00	0.00	0.31	37.7	40.1	54.0	94.1	-14.7
Moke 14	3.07	0.04	0.00	0.33	23.1	26.5	42.7	69.2	-23.4
Lower Cole Ck	3.07	0.04	0.00	0.33	38.7	42.1	56.0	98.0	-14.2
Wahoo East	1.61	0.00	0.00	4.73	69.9	76.3	81.3	157.6	-3.2
Wahoo East	1.33	0.00	0.00	3.41	74.7	79.6	81.8	161.4	-1.4
Cascade	0.87	0.00	0.00	1.96	24.3	27.1	38.9	66.1	-17.9

LAKE NAME	ueq/L CL	ueq/L NO2	ueq/L NO3	ueq/L SO4	ueq/L [ANC]	SUM ANIONS	SUM CATIONS	TOTAL ION	%ION DIFF
Cascade	0.87	0.00	0.00	2.19	31.2	34.3	38.9	73.2	-6.3
Cascade	0.93	0.04	0.00	2.39	27.0	30.3	37.3	67.6	-10.3
Cascade	0.99	0.04	0.00	2.52	33.4	36.9	36.5	73.4	0.6
Moat (shoreline)	2.06	0.04	0.00	14.49	62.2	78.8	85.8	164.5	-4.3
Moat (shoreline)	3.10	0.00	0.00	16.03	59.5	78.6	90.4	169.0	-6.9
Moat (mid-lake)	2.45	0.07	0.00	16.20	62.4	81.1	91.8	172.8	-6.2
Moat (mid-lake)	2.34	0.00	0.00	11.41	60.9	74.8	89.0	163.8	-8.7
Dana Duplicate	2.57	0.00	17.84	129.69	23.1	173.8	166.1	339.9	2.3
Dana	2.65	0.00	17.77	130.53	19.6	171.1	167.9	339.1	0.9
Little East Marie	0.65	0.07	1.02	6.97	22.3	30.9	38.6	69.5	-11.1
Little East Marie	0.79	0.04	1.02	3.02	18.5	23.3	37.9	61.2	-23.8
Powell	4.17	0.00	0.00	2.56	26.0	33.3	46.4	79.7	-16.5
Powell Duplicate	4.09	0.00	0.00	2.58	27.6	34.8	45.3	80.1	-13.0
Cascade	1.30	0.00	0.00	4.23	51.2	57.8	66.6	124.3	-7.1
Cascade	1.21	0.00	0.00	4.46	51.7	58.3	66.4	124.7	-6.4
Treasure	1.66	0.09	0.00	3.52	52.4	58.3	65.6	123.9	-5.9
Treasure	1.66	0.00	0.02	4.21	54.5	61.2	66.0	127.2	-3.8
East Chain	0.08	1.00	0.00	0.17	-6.4	-6.1	8.1	2.0	-718.7
Caribou #8	0.31	1.57	0.00	0.12	0.9	1.4	5.2	6.6	-58.7
Hubbard	0.23	1.52	0.00	0.08	1.9	2.2	5.6	7.8	-44.1
Waca	0.14	0.00	0.00	0.12	5.5	5.8	5.6	11.4	1.5
Smith	0.48	0.00	0.00	0.19	5.4	6.1	5.0	11.1	9.4
Lower Cole Ck	3.33	0.00	0.00	0.42	5.8	9.6	5.6	15.2	26.5
Wahoo East	0.00	0.00	0.00	0.15	6.9	7.1	4.4	11.5	23.2

LAKE NAME	SUM BASES	SUM ACIDS	DIFF= ALK	FLAG %ION	% COND DIFF	FLAG % COND	THEOR. COND
Long	55.2	4.1	51.0	OK	0.6	OK	5.4
Long	55.0	4.9	50.1	OK	2.2	OK	5.4
Long	55.5	4.9	50.6	OK	3.3	OK	5.4
Long	56.0	5.3	50.7	OK	4.1	OK	5.6
Bullfrog	40.0	4.5	35.6	OK	-1.2	OK	3.8
Bullfrog	40.8	2.6	38.2	OK	-1.9	OK	3.7
East Chain	56.3	4.1	52.2	OK	4.2	OK	5.3
East Chain	64.8	4.5	60.3	OK	5.8	OK	6.1
East Chain	58.5	5.9	52.6	OK	-3.5	OK	5.5
East Chain	64.9	5.4	59.4	OK	-1.2	OK	6.2
Vermilion	53.3	6.3	47.1	OK	2.3	OK	5.2
Vermilion	55.9	6.3	49.6	OK	3.7	OK	5.3
Caribou #8	39.4	3.2	36.3	OK	-6.9	OK	3.7
Caribou #8	39.5	3.2	36.3	OK	-0.9	OK	3.9
Walton	26.9	13.2	13.7	OK	2.9	OK	3.5
Hufford	51.8	7.3	44.5	OK	1.1	OK	5.3
Hufford	54.4	7.3	47.1	OK	4.1	OK	5.5
Walton Dup	24.3	12.8	11.5	OK	-7.9	OK	3.3
Powell	40.3	5.4	34.9	OK	1.1	OK	3.6
Powell Dup	38.4	5.6	32.8	OK	8.3	OK	3.9
Powell	79.0	9.4	69.6	OK	0.6	OK	8.1
Powell Dup	79.9	9.6	70.4	OK	-3.8	OK	8.2
Powell	38.0	5.3	32.7	OK	6.0	OK	3.9
Powell Dup	36.1	5.5	30.6	OK	2.7	OK	3.5
Waca	23.0	4.5	18.5	OK	-4.0	OK	2.8
Waca	22.0	4.8	17.2	OK	-4.9	OK	2.8
Karls	27.6	3.2	24.5	OK	-12.7	OK	2.7
Karls	28.6	3.0	25.6	OK	-8.5	OK	2.8
Smith	27.8	5.8	22.1	OK	-12.9	OK	2.7
Smith	29.4	6.0	23.4	OK	-3.4	OK	3.0
Smith	29.8	6.3	23.6	OK	-8.3	OK	3.0
Smith	28.0	6.1	21.8	OK	-6.1	OK	2.8
Treasure	52.7	14.3	38.4	OK	1.1	OK	5.3
Bench	124.9	45.8	79.2	OK	6.1	OK	13.0
Treasure	50.7	14.7	36.0	OK	1.7	OK	5.4
Treasure	50.3	13.8	36.6	OK	1.8	OK	5.2
Treasure	51.6	14.2	37.4	OK	2.4	OK	5.4
Key Lake	16.7	6.0	10.7	OK	19.2	OK	2.2
Key Lake	15.0	6.3	8.8	OK	10.2	OK	2.0
Bench	121.4	46.9	74.5	OK	0.1	OK	12.7
Moke 14	46.7	6.1	40.6	OK	-4.5	OK	4.3
Lower Cole Ck	53.4	2.4	51.0	OK	-12.2	OK	4.8
Moke 14	40.8	3.4	37.4	OK	-20.8	OK	3.8
Lower Cole Ck	55.5	3.4	52.0	OK	-5.2	OK	5.0
Wahoo East	80.8	6.3	74.4	OK	-4.8	OK	7.8
Wahoo East	81.8	4.7	77.0	OK	2.6	OK	7.9
Cascade	38.7	2.8	35.8	OK	-3.1	OK	3.4

LAKE NAME	SUM BASES	SUM ACIDS	DIFF= ALK	FLAG %ION	% COND DIFF	FLAG % COND	THEOR. COND
Cascade	38.6	3.1	35.5	OK	4.3	OK	3.7
Cascade	37.0	3.3	33.7	OK	-2.6	OK	3.4
Cascade	35.9	3.5	32.4	OK	6.9	OK	3.7
Moat (shoreline)	85.7	16.6	69.1	OK	1.3	OK	8.4
Moat (shoreline)	90.3	19.1	71.1	OK	2.9	OK	8.7
Moat (mid-lake)	91.7	18.7	73.0	OK	4.7	OK	8.9
Moat (mid-lake)	88.9	13.8	75.2	OK	-2.9	OK	8.3
Dana Duplicate	165.4	150.1	15.3	OK	5.6	OK	20.6
Dana	167.4	151.0	16.4	OK	3.9	OK	20.5
Little East Marie	38.0	8.6	29.4	OK	-21.8	OK	3.8
Little East Marie	37.4	4.8	32.5	OK	-29.2	OK	3.3
Powell	46.0	6.7	39.2	OK	3.3	OK	4.2
Powell Duplicate	44.8	6.7	38.1	OK	7.4	OK	4.2
Cascade	66.4	5.5	60.9	OK	18.9	OK	6.1
Cascade	66.2	5.7	60.5	OK	23.5	OK	6.1
Treasure	65.5	5.2	60.3	OK	16.6	OK	6.2
Treasure	65.9	5.9	60.0	OK	17.4	OK	6.3
East Chain	3.2	0.3	3.0	Check	-10.0	OK	1.4
Caribou #8	1.1	0.4	0.7	OK	-12.5	OK	1.4
Hubbard	1.3	0.3	1.0	OK	2.6	OK	1.4
Waca	0.9	0.3	0.7	OK	-14.2	OK	1.6
Smith	1.4	0.7	0.8	OK	-0.8	OK	1.4
Lower Cole Ck	2.2	3.7	-1.6	OK	21.3	OK	1.8
Wahoo East	1.0	0.1	0.9	OK	11.2	OK	1.4